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VOLUME 16 PART 1

Large Scale Variety Trials of Hevea brasiliensis Muell-Arg. on Malayan Estates 1934-53

H. M. BURKILL *

*Yields from virgin bark and also some important secondary characteristics (girth, virgin bark thickness and renewal, resistance to brown bast) of a large number of cultivars of Hevea brasiliensis are reported and discussed**. The information has been obtained from numerous trials, each statistically designed and conducted according to commercial practice, on estates throughout Malaya. The work continues and further reports will be available later.*

The slump of 1930 gave rise to a major problem for the planting industry: how to economise in the cost of production of rubber on estates. Although this period was characterised by over-production of natural rubber, the obvious source of economy lay in the development and selection of higher-yielding material.

The improvement of yield of *Hevea brasiliensis* in general and the progress of breeding and selection carried out by the Rubber Research Institute of Malaya have previously been described (SANDERSON AND SUTCLIFFE 1929, SHARP 1940, SHARP 1951, BAPTIST 1953). The purpose of this paper is to discuss the performance of the planting material which such selection made available to the industry.

The Rubber Regulation Scheme was a result of the depression years. It was an agreement (H.M. STATIONARY OFFICE 1934) between the governments of the major rubber-producing countries in South East Asia to regulate the production and export of rubber. Article 12 made provision for small areas in countries joining the Scheme to be planted exclusively for experimental purposes. The area allowed was limited to one quarter of one per cent of each country's total planted acreage. For Malaya, including Singapore and Brunei, this was approximately 8,000 acres.

It was under these circumstances that the experimental planting of 1934-1941 on estates in Malaya was established, most of it by agreement and collaboration between the estate owners and the Rubber Research Institute. By the end of 1941, when South East Asia was invaded, 6,000 acres had been allocated to the Botanical Division of the Rubber Research Institute of Malaya and on this acreage one hundred and eight trials had been established. Eighty-nine trials were for testing planting material on a large scale.

During the period of reconstruction after the occupation of Malaya, forty-six of these trials were re-established and records obtained. On the following pages details from most of these trials will be given.

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** This report is a condensation of a longer paper, *Research Archives of the Rubber Research Institute of Malaya, Document No. 10 Parts 1 and 2, 1958.* Copies of the longer paper can be obtained on request from the Botanical Division of the Institute: the number available for issue is limited, but copies can be supplied on loan. A preliminary paper on the results of this work was read at the Conference of Rubber Research Institutes in the Far East held at Bogor, Java, on July 15-17, 1952 (BURKILL 1953).

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EXPERIMENTAL METHOD

The Material Under Test

Old clones. The development of budgrafting led to the selection and making of clones from high-yielding seedling trees and from 1917 onwards many thousands were developed. Most failed to reproduce the performance of their mother trees, and, as more proof was obtained, the numerous selections were culled until in 1935 only a few remained to be recommended for large-scale planting. The Institute's advice for the use of clones soon after the time of the establishment of experimental planting under the Rubber Restriction Scheme mentioned twelve clones only (R.R.I.M. 1939). Nine of them, together with two other clones, are represented in these trials and constitute one class of material tested, known as the 'old clones'. They are:

Malayan clones

Pilmoor B84 (Pil B84)	Prang Besar 186 (PB 186)
Pilmoor D65 (Pil D65)	Sabrang 24 (Sab 24)
Glenshiel 1 (Gl 1)	Rubana 393 (Rub 393)
Prang Besar 86 (PB 86)	Lunderston N (Lun N)

Javan clones

Tjirandji 1 (Tjir 1)
Tjirandji 16 (Tjir 16)
Bodjong Datar 5 (BD 5)

Seedling families. The second class of material tested consists of twenty-nine families of seedlings. These are derived, in the main, from early clonal selections (from which the old clones are taken) and are their first generation descendants, (F_1). The seed is described as coming from different parent areas as indicated below.

When budgrafting became an established estate practice during the years 1920-30, many areas were planted with mixed clones and were known as polyclonal blocks; later as confidence grew in individual clones, monoclonal blocks were budded. From the mixed clonal plantings there were thirteen families of seedlings for trial (including four whose seed had been sorted for mother tree type); and from monoclonal areas, seven families.

About the same time as the development of budgrafting, the technique and results of hand pollination were studied. Investigations into the performance of high-yielding clones as seed parents led to the selection of certain clones, not necessarily the best yielders, thought to pass on a capacity for high yield to their seedlings, for budding in seed gardens. The progenies from six such seed gardens are represented in these trials.

There are also three families of second generation seedlings, (F_2).

The names of the seedling families tested are shown in Table 1 and the sources of origin of mixed and illegitimate seed in Table 2.

New clones (RRIM clones). The third category of material under test consists mainly of clones made from hand-pollinated seedlings of the 1929 breeding programme of the Rubber Research Institute (SANDERSON AND SUTCLIFFE 1929). These clones are the thirty of the RRIM 500 series. Also tested under RRIM numbers are eleven clones made originally from high-yielding mother trees from estates. These clones were planted first in a small scale in Field 15 of the R.R.I.M. Experiment Station and selected for large-scale trial from the 235 clones budded there.*

Distribution of Trials in Malaya and their Design

Many trials established could not be reconstructed after the neglect of the war-time occupation of Malaya; although rehabilitation of some areas was fully carried out, the extra supervision required on experimental areas became impossible owing to terrorism. However, sufficient trials were brought into recording to test the new material. A list is given in

* These clones should strictly come in the category of 'old clones' since the mother trees are of unselected seedling origin. In these trials however these clones are tested with the clones of the RRIM 500 series. For convenience of reporting they are included with the 'new clones'. All new clones are referred to as 'RRIM clones'.

TABLE 1. SEEDLING FAMILIES UNDER TRIAL

The total number of families is twenty-nine, not including PBISG 'CDE' which is a mixture of three families.

Parent areas	Polyclonal blocks			Monoclonal blocks	Seedling areas
Family type	Mixed	Illegitimate (seed sorted for mother tree type)	Seed garden	Selfed	'Second generation'
Family names	Batu Kawan	PB 86	Labu	Tjir 1	RRIES Fd 2
	Bukit Rajah	SR 9	Chemara 'B'	Tjir 16	RRIES Fd 4A
	Gadek	RRIM 507	PBISG 'C'	Gl 1	RRIES Fd 16N
	Bulok Akar	Sembrong (AVROS 163)	PBISG 'D'	BD 5	
	St. Helier		PBISG 'E'	Sab 24	
	RRIES Fd 14AB		PBISG 'CDE' (mixed)	Rub 393	
	RRIES Fd 15N				
	RRIES Fd 18		Pilmoor duoclone	PB 25	
	RRIES Fd 22				

TABLE 2. PARENTAGE OF FAMILIES OF POLYCLONAL AND SEEDLING ORIGIN

Family		Parentage
Polyclonal		
(a) Mixed	Batu Kawan	PB 23, 25, 186; AVROS 49, 157, 256; BD 5; Batu Kawan 44, 117.
	Bukit Rajah	PB 86, 123; BD 5, 10; AVROS 49, 50.
	Gadek	Tjir 1, 10, 16; BD 5, 10; AVROS 49, 80, 256; clone X (no name).
	Buloh Akar	AVROS 49, 163; Tjir 1.
	St. Helier	PB 23, 25, 123, 155, 186; SR 9.
	RRIES Fd 14AB	AVROS 50; clones from legitimate seedlings made from crosses of Pilmoor clones, Lun N and K. (From these 30 were selected for test under RRIM 500 series numbers).
	RRIES Fd 15N	Museum block containing a miscellany of old clones.
	RRIES Fd 18	PB 25, 180, 186; Gl 1; Sab 24; Rub 393; SR 9; Pil B84; BD 2, 5, 10; Tjir 1, 16; AVROS 49, 50, 152, 256.
	RRIES Fd 22	AVROS 49, 152; Tjir 1; Rub 393; PB 186.
(b) Illegitimate	PB 86	RRIES Fds 15 and 20 } The clones in these fields are planted in single rows or small groups. Crossing with a wide variety of old clones is possible.
	SR 9	RRIES Fd 18 }
	RRIM 507	See above — RRIES Fd 14AB
	Sembrong (AVROS 163)	AVROS 163. (Possible pollen parents: SR 9; K10; AVROS 33, 36, 49, 50, 71, 80, 152, 157, 163; BD 5.)
(c) Seed Gardens	Labu	BR 1, 2; AVROS 152.
	Chemara 'B'	AVROS 49*, 157; Tjir 1.
	PBISG 'C' PBISG 'D' PBISG 'E'	Clonal compositions not published.
	Pilmoor duoclone	Pil A44, B84.
Seedling		
	RRIES Fd 2	Tjikadoe seedlings.
	RRIES Fd 4A	Legitimate and illegitimate seedlings of Pilmoor clones (RRIM 1928 breeding programme).
	RRIES Fd 16N	Legitimate and illegitimate seedlings of Pilmoor clones (RRIM 1929 breeding programme). These are the mother trees of the clones in RRIES Fd 14AB and contain the mother trees of the RRIM 500 series clones.

* AVROS 49 has now been thinned out.

Table 3 of estates from which the results reported here have been obtained.

The categories of the material tested have been noted above. On four estates, Nos. 9, 16, 28 and 41, material from all three has been planted. On four other estates, Nos. 35, 58, 99 and 165, there are trials of the second and third categories, while the remainder have single trials.

The design of nearly all these trials has conformed to statistical requirements. A randomised block design has been the one most used, generally with ten treatments (planting material) and five replications, though other

TABLE 3. DETAILS OF ESTATES AND DESIGN OF TRIALS

Estate details				Design			
				Old clones			
Estate No.	District	Soil type	Topography	Main trials	Subsidiary trials	Seedling families	RRIM clones
New plantings on virgin land							
RRIES Fd 30A	Selangor, central	Inland	Undulating	—	—	—	r. b.
,, Fd 30B	Selangor, central	Inland	Undulating	—	—	—	r. b.
,, Fd 38B	Selangor, central	Inland	Steep	—	—	—	r. b.
No. 7	Perak, central	Inland	Steep	—	—	r. b.	—
9	Johore, central	Inland	Undulating	l. s.	r. b.	b. i. b.	b. i. b.
14	Selangor, central	Inland	Undulating	—	—	—	r. b.
16	Pahang, west	Inland	Undulating to steep	l. s.	r. b.	b. i. b.	b. i. b.
27	Johore, south	Inland	Steep	—	—	—	r. b.*
28	Selangor, coastal	Alluvial clay, peat	Flat	l. s.	r. b.	r. b.	r. b.
35	Perak, north	Inland	Undulating	—	—	r. b.	r. b.
39	N. Sembilan, east	Inland	Flat	—	—	—	r. b.
41	Dindings, coastal	Alluvial clay	Flat	l. s.	r. b.	b. i. b.	b. i. b.
43	Selangor, coastal	Alluvial clay, peat	Flat	—	—	—	r. b.
44	Pahang, central	Inland	Flat	—	—	—	r. b.
58	N. Sembilan, north	Inland	Undulating to steep	—	—	r. b.*	r. b.
62	N. Sembilan, east	Inland	Flat	—	—	r. b.*	—
73	Selangor, coastal	Inland	Steep	—	—	—	r. b.*
78	N. Sembilan, east	Inland	Undulating	—	—	l. s.	—
99	Malacca	Inland	Undulating	—	—	r. b.	r. b.
100	Kedah, south	Inland	Undulating	—	—	r. b.	—
122	Perak, north	Inland	Very steep	—	—	—	r. b.
165	Johore, central	Inland	Undulating	—	—	r. b.	r. b.
175	Kelantan	Inland	Steep	—	—	—	s. l.
Replantings							
a/1	Perak, central	Inland	Undulating	—	—	—	o. p*
a/2	Perak, coastal	Alluvial clay	Flat	—	—	—	r. b.
a/3	Selangor, central	Inland, alluvium	Flat	—	—	—	o. p*
a/4	N. Sembilan, north	Inland	Undulating	—	—	—	r. b.
a/7	Selangor, central	Inland	Flat	—	—	—	o. p.

l.s. latin square design
r.b. replicated block design
b.i.b. balanced incomplete block design
s.l. simple lattice design
o.p. observation plots
* yield records from these trials are not quoted, but records of secondary characters have been incorporated in this report

designs have also been employed. Brief details are given in Table 3.

Planting and General History

All trials were planted between 1936 and 1940. Felling, burning and clearing of the jungle for new plantings followed normal estate practice. Areas were lined to give a stand of 180 points per acre. For contour planting the spacing approximated to 22 ft × 11 ft, while on flat land planting was rectangular and at spacings which conformed with drainage requirements.

In most areas for testing clones, unselected seed was germinated and planted at stake in 2-ft-cube planting holes for field budding. One estate, No. 28, planted seedling stumps, and another, No. 41, planted budded stumps. These variants followed their respective normal estate practice.

Any good standard method of cultivation with leguminous, indigenous, or mixed covers was followed and applied uniformly to the whole area.

After planting of the clone trial areas was complete, and before planting but after lining in the clonal seedling trial areas, the plots were demarcated. When growth of the seedling stocks of the former (except on estate 41) permitted they were budded and when adequate successfully budded points were obtained in the field, cutting back and supplying was carried out.

The clonal seedling trials were supplied with seed collected from the selected areas on estates and germinated on the R.R.I. Experiment Station. The seedling families were planted during one planting season, except on estate No. 58 where two blocks destroyed by fire during the first year were replanted in the following year. At the same time germinated unselected seed was planted in the control plots for growing stocks for budding the control, which was carried out when the stocks had attained sufficient size. On estate 41, however, budded stumps were planted at the same time as the clonal seed.

The details of the early growth of the material in these trials is almost entirely lost: what has survived the war is disconnected and of little consequence. Also lost was the opportunity to give the areas the benefit of normal husbandry at the appropriate time. Thinning out, which would normally have been begun at an earlier age, was not done until the trials came into tapping—which was itself delayed. Thus in most of the trials the stands had reached the age of 8-10 years before being reduced to 150 trees per acre. After the third year of tapping uneconomic trees were removed to give a stand of about 135 trees per acre. Not only did the trials suffer delayed thinning out; uncontrolled regeneration of forest plants led in many cases to acute competition for existence, so that the trees in general were retarded.

Recording and Records

Planting material is selected for its yield and this is its primary character. Vegetative characters, though important, are termed secondary, and while it is obviously better that these should conform to desirable standards, the breeder of high-yielding material usually has to accept some secondary characteristics which fall below the ideal.

The characters which have been recorded in these trials are:

1. Girth
2. Incidence of brown bast
3. Virgin bark thickness and rate of first renewal
4. Yield from virgin bark

Items 1, 3 and 4 above have been analysed for differences between the effect of coastal and inland soils. In presenting these data, the effect of the war-time occupation of Malaya is necessarily an unknown quantity. Because of this, more weight should be attached to relative than to actual values of varietal results in each set of records.

Age of Trees

The age of budgrafts normally is reckoned from the time of budding in the field, or from the time of planting as budded stumps, and the age of seedlings from the time of planting the seed. In the seedling trials, however, the recorded age of the budded control is equal to

that of the seedlings, that is, it is reckoned from the date of planting the seed for stocks. To obtain the age of the control as normally calculated, the time taken to grow the stocks to buddable size should be deducted from the recorded age. The seedling families are therefore being compared with a budded control younger than they are, though the corresponding comparison in the clone trials is between material of equal age.

The comparison of the seedlings with their control is an economic one since it includes the total time of occupation of the land. In the clone trials the extra time required to grow seedling stocks for budding is not taken into consideration, since there is no age difference between the clones and their control. If however a comparison is made between the performance in relation to the respective control of clonal seedling and budded material there is bias in favour of the former which limits the validity of the comparison.

Presentation of Results

For convenience in presentation and discussion the secondary characteristics are dealt with first and results are given in the following order: girth; brown bast, virgin bark thickness, and first renewal; yield.

GIRTH

Girth measurements have been recorded at 50 in. from the union on budgrafts, and at 50 in. from the ground on seedlings. No record is available of girths during immaturity and the records summarised were those taken at some time between 10 and 14 years of age. Age at measurement was constant for all varieties in a given trial but was not the same for all trials.

All varieties have not been tested on the same sites nor even on the same number of sites, and consequently varietal comparisons based on observed mean girths for each variety are likely to be heavily biased because of site differences. However, with one exception, each trial included clone Pil B84 as control, and adjusted mean girths have been derived for each variety by considering its girths relative to the corresponding controls. More explicitly, the adjusted mean girth of any variety, $\bar{t}$, on inland soils is calculated as:

$$\bar{g}_t = \bar{r}_t \times \bar{g}_o$$

Where $\bar{g}_o$ = the mean girth of the control clone Pil B84 averaged over all the trials on inland sites, (each trial being given equal weight)

$\bar{r}_t$ = the mean ratio of the girth of variety $\bar{t}$ to the girth of the control, averaged over those inland trials involving variety $\bar{t}$.

Varietal comparisons in terms of these adjusted mean girths will not be biased by site differences provided there is no marked variety $\times$ site interaction over the inland trials. The adjustment also helps to correct for the fact that girths were not measured at the same age on all the inland sites; these age discrepancies merely contribute to the site differences. Adjusted girths have been derived in the same way for the varieties tested on coastal sites.

Varietal Comparisons

The observed and adjusted mean girths of each variety on inland and coastal soils are summarised in Table 4. Rankings, based on adjusted girths, are given separately for old clones, RRIM clones, and clonal seedlings and for the three groups combined. Adjustments tend to be more pronounced for those varieties tested on only a few sites because their observed mean girths were more readily influenced by an exceptional site. In the clonal seedling group on inland soils the adjustments have usually increased the observed values, and this is partly due to the fact that the control clone in these trials generally had about one year's less growth than in the other trials on inland soil.

TABLE 4(A). MEAN GIRTHS ON INLAND AND COASTAL SOILS. OLD CLONES

Old clones, inland						Old clones, coastal					
Rank within group	Variety	No. of trials	Observed mean girth (in.)	Adjusted mean girth (in.)	Overall rank	Rank within group	Variety	No. of trials	Observed mean girth (in.)	Adjusted mean girth (in.)	Overall rank
1	Tjir 1	3	27.2	27.0	35	1	Sab 24	2	31.2	30.8	11
2	Rub 393	2	27.7	27.0	36	2	Lun N	2	31.3	30.5	12
3	Sab 24	1	30.3	26.8	40	3	Tjir 1	2	30.3	29.9	20
4	Pil D65	2	26.8	26.0	48	4	Pil B84	8	29.6	29.6	25
5	Pil B84	31	25.9	25.9	50	5	Gl 1	2	29.8	29.4	27
6	Tjir 16	2	26.4	25.6	52	6	Rub 393	2	29.6	29.2	29
7	PB 86	3	26.3	25.1	56	7	Pil D65	2	29.4	29.0	32
8	PB 186	1	28.3	25.0	59	8	PB 186	2	28.1	27.6	42
9	Lun N	1	22.8	24.8	63	9	PB 86	2	27.3	26.8	47
10	Gl 1	2	24.0	23.4	76	10	Tjir 16	2	27.2	26.8	48
11	BD 5	2	22.3	21.7	80	11	BD 5	2	25.1	24.6	52
Unweighted group mean (adjusted girth) 25.30 ± 0.49						Unweighted group mean (adjusted girth) 28.56 ± 0.57					

TABLE 4(B). MEAN GIRTHS ON INLAND AND COASTAL SOILS. RRIM CLONES

RRIM clones, inland

Rank within group	Variety	No. of trials	Observed mean girth (in.)	Adjusted mean girth (in.)	Overall rank
1	RRIM 528	2	29.4	28.7	21
2	520	5	28.9	28.6	22
3	218	2	29.2	27.5	30
4	178	3	27.2	27.4	31
5	195	2	29.1	27.4	32
6	516	5	27.3	27.0	34
7	524	1	27.8	26.9	37
8	505	8	28.3	26.8	38
9	142	4	27.8	26.8	39
10	507	6	27.6	26.6	42
11	138	2	29.0	26.6	43
12	5	2	25.0	26.5	44
13	502	8	26.8	26.4	45
14	519	9	26.2	26.3	46
15	515	8	25.7	26.0	47
16	49	2	26.4	26.0	49
17	525	2	26.5	25.8	51
18	506	6	26.0	25.3	53
19	107	3	26.3	25.3	54
20	511	4	25.6	25.1	55
21	526	1	26.0	25.1	57
22	518	8	25.8	25.0	58
23	500	12	25.3	24.9	60
24	508	3	25.9	24.9	61
25	522	1	26.3	24.9	62
26	512	6	25.0	24.7	64
27	503	5	25.0	24.7	65
28	523	3	24.9	24.7	66
29	147	1	27.5	24.7	67
30	527	2	26.2	24.5	68
31	501	14	24.8	24.3	69
32	513	7	24.1	24.2	70
33	529	2	26.4	24.0	71
34	517	3	24.2	23.8	72
35	504	7	24.2	23.7	73
36	521	3	24.1	23.6	74
37	99	2	23.8	23.5	75
38	509	8	23.4	23.0	77
39	514	8	23.1	22.7	78
40	27	1	26.3	22.4	79
41	510	4	21.8	21.5	81

Unweighted group mean (adjusted girth) 25.31 ± 0.26

" " " excluding those varieties not occurring in both inland & coastal trials 24.98 ± 0.36

RRIM clones, coastal

Rank within group	Variety	No. of trials	Observed mean girth (in.)	Adjusted mean girth (in.)	Overall rank
1	RRIM 505	2	33.6	33.2	1
2	515	2	32.0	31.6	4
3	507	2	31.1	30.8	9
4	519	2	31.0	30.8	10
5	520	1	30.7	30.3	14
6	518	3	30.3	30.2	15
7	502	1	30.2	29.7	22
8	511	3	29.8	29.6	24
9	500	4	29.3	28.9	33
10	508	1	29.2	28.9	34
11	506	4	29.1	28.7	35
12	512	1	28.8	28.4	38
13	501	4	28.6	28.2	39
14	522	2	27.5	27.3	43
15	503	1	27.5	27.1	44
16	513	3	27.4	27.0	45
17	504	3	27.4	26.8	46
18	509	1	27.0	26.6	49
19	514	4	26.2	25.9	50
20	510	1	25.7	25.3	51

Unweighted group mean (adjusted girth) 28.77 ± 0.46

" " " excluding those varieties not occurring in both inland & coastal trials 28.76 ± 0.46

TABLE 4(C). MEAN GIRTHS ON INLAND AND COASTAL SOILS. CLONAL SEEDLINGS

Clonal seedlings, inland

Rank within group	Variety	No. of trials	Observed mean girth (in.)	Adjusted mean girth (in.)	Overall rank
1	RRIES Fd 2	2	29.2	32.6	1
2	Rub 393	2	28.6	31.9	2
3	B. Kawan	8	29.3	31.4	3
4	Buloh Akar	2	28.0	31.3	4
5	RRIES Fd 22	2	28.0	31.3	5
6	Gadek	2	27.5	30.8	6
7	Tjir 1 selfed	9	28.4	30.7	7
8	PB 25 selfed	2	29.1	30.7	8
9	PBISG 'CDE'	6	28.4	30.5	9
10	RRIES Fd 16N	4	28.4	30.1	10
11	RRIES Fd 18	7	28.3	29.9	11
12	Gl 1 selfed	5	26.4	29.9	12
13	Tjir 16 selfed	2	26.7	29.9	13
14	Sembrong	1	31.3	29.9	14
15	RRIES Fd 4A	5	27.2	29.7	15
16	Pilmoor	9	27.8	29.5	16
17	PBISG 'C'	2	31.4	29.5	17
18	Bt. Rajah	5	28.6	29.3	18
19	PBISG 'D'	3	28.8	29.1	19
20	PBISG 'E'	2	31.0	29.1	20
21	St. Helier	1	31.0	28.6	23
22	SR 9 illeg.	4	26.5	28.5	24
23	Labu	1	29.9	28.5	25
24	Chemara B	1	29.9	28.5	26
25	RRIES Fd 14AB	8	26.9	28.4	27
26	Sab 24 selfed	2	25.4	28.4	28
27	PB 86 illeg.	2	26.0	28.0	29
28	RRIES Fd 15N	3	25.1	27.1	33
29	BD 5 selfed	3	24.2	26.7	41

Unweighted group mean (adjusted girth) 29.65 ± 0.26

" " " excluding those varieties not occurring in both inland & coastal trials 29.94 ± 0.33

Clonal seedlings, coastal

Rank within group	Variety	No. of trials	Observed mean girth (in.)	Adjusted mean girth (in.)	Overall rank
1	B. Kawan	2	31.0	32.5	2
2	PBISG 'CDE'	2	30.2	31.7	3
3	Pilmoor	1	27.9	31.4	5
4	Tjir 1 selfed	2	29.8	31.3	6
5	RRIES Fd 18	2	29.6	31.1	7
6	RRIES Fd 2	1	31.9	31.1	8
7	Rub 393 selfed	1	31.4	30.5	13
8	Bt. Rajah	2	28.8	30.2	16
9	RRIES Fd 4A	2	28.8	30.2	17
10	RRIES Fd 14AB	2	28.7	30.1	18
11	Sab 24 selfed	1	30.9	30.1	19
12	BD 5 selfed	2	28.6	29.7	21
13	RRIES Fd 22	1	30.6	29.7	22
14	Gl 1 selfed	1	30.3	29.5	26
15	Buloh Akar	1	30.2	29.4	28
16	Gadek	1	30.0	29.2	30
17	RRIM 507 illeg.	1	29.9	29.1	31
18	SR 9 illeg.	1	29.5	28.7	36
19	Tjir 16 selfed	1	29.3	28.5	37
20	PB 86 illeg.	1	28.9	28.1	40
21	RRIES Fd 16N	1	28.9	28.1	41

Unweighted group mean (adjusted girth) 30.01 ± 0.26

" " " excluding those varieties not occurring in both inland & coastal trials 30.06 ± 0.27

The rankings within the group of old clones confirm previous ideas derived from commercial plantings. They demonstrate, for example, the relative vigour on both inland and coastal plantings of clone Tjir 1, and the lack of it in clones PB 86 and BD 5. The inferiority of clone Gl 1 on inland soil is also noteworthy. A few of the RRIM clones (e.g., RRIM 107, 501, 513, 526 and 527) and some of the clonal seedling families (e.g., PBISG 'C D E', Pilmoor, Tjir 1 selfed, PB 86 illegitimate) have been extensively planted commercially and it is of interest to see how their growth compares with that of the lesser known material within their respective groups. None of the above RRIM clones can be regarded as a vigorous member of the RRIM group, and PB 86 illegitimate seedling family is a distinctly inferior member of the clonal seedling group in terms of growth. However, PBISG 'C D E', Tjir 1 selfed and Pilmoor are among the outstandingly vigorous clonal seedlings in coastal plantings, and PBISG 'CDE' and Tjir 1 selfed also grow relatively well on inland soils.

Many of the varieties listed in Table 4 have been tested on inland and coastal soils, and the majority of these varieties can be regarded as occupying roughly the same order of rank within their group on both soil types. Some, however, interact markedly with soil type, and their girth ranking within their particular group on inland soil differs noticeably from their rank on coastal soil. In this connection the most noteworthy results are set out below:

Relatively more vigorous on inland than on coastal soil :

Old clones:	Tjir 16, Rub 393
RRIM clones:	nil
Clonal seedlings:	Buloh Akar, Gadek, RRIES Fd 16N

Relatively more vigorous on coastal than on inland soil :

Old clones:	Lun N, Gl 1
RRIM clones:	nil
Clonal seedlings:	Pilmoor, BD 5 selfed, Sab 24 selfed, RRIES Fd 14AB

Relatively good growth within their particular group on both soil types :

Old clones:	Tjir 1, Sab 24
RRIM clones:	505, 507, 515, 519, 520
Clonal seedlings:	RRIES Fd 2, Rub 393 selfed, Batu Kawan, Tjir 1 selfed

Relatively inferior growth within their own group on both soil types :

Old clones:	BD 5, PB 186
RRIM clones:	503, 504, 509, 510, 513, 514
Clonal seedlings:	SR 9 illegitimate, PB 86 illegitimate

Comparison of Growth of Clones and Seedlings

The trial results confirm the general belief that seedlings are usually more vigorous than clones. Table 5(a), which is derived from measurements of all the varieties tested, summarises the adjusted mean girths of each group on inland and coastal soils. On inland plantings the average girth of the twenty-nine clonal seedling families significantly exceeds that of either of the clonal groups by some four inches. On coastal sites, the clonal seedling group mean is still significantly greater than any of the clonal groups, although the difference only just exceeds one inch.

Within each seedling trial (with one exception which will be discussed later), the clonal seedlings and the stocks for budding the control clone were planted together and subsequently measured simultaneously. Thus in these comparisons, the age of the seedlings from planting is equal to the age of the stocks of the buddings. The adjusted girths correspond to an age of just over 12 years from planting.

Comparison of Growth on Inland and Coastal Soils

In Table 5(b) a similar group summary is given, but only those varieties which have been tested on both inland and coastal sites are included. The average age of measurement of the coastal trials is practically the same as that of the inland ones, and the

TABLE 5. ADJUSTED MEAN GIRTHS (INCHES) BY GROUPS ACCORDING TO LOCATION

(a) Including all varieties

Group	Inland			Coastal		
	Number of varieties	Mean girth (± s.e.)	Variance between varieties	Number of varieties	Mean girth (± s.e.)	Variance between varieties
Old clones	11	25.3 (± 0.5)	2.6	11	28.6 (± 0.6)	3.6
RRIM clones	41	25.3 (± 0.3)	2.7	20	28.8 (± 0.5)	4.2
Clonal seedlings	29	29.6 (± 0.3)	1.9	21	30.0 (± 0.3)	1.4
(b) Including only those varieties tested on both inland and coastal soils						
Old clones	11	25.3 (± 0.5)	2.6	11	28.6 (± 0.6)	3.6
RRIM clones	20	25.0 (± 0.4)	2.5	20	28.8 (± 0.5)	4.2
Clonal seedlings	20	29.9 (± 0.3)	2.1	20	30.1 (± 0.3)	1.5

following comparisons of soil type can be regarded as almost free of confounding with varietal or age effects.

The average girth at about 12 years of age of the old clones group on coastal soils is some three inches more than that of the same group of clones on inland soil. A similar highly significant difference is observed between coastal and inland soils for the RRIM clones. For clonal seedlings, however, the difference between average girths on the two soil types is small and the superiority of the coastal sites is not established with confidence.

An error of bias. One coastal estate with trials of old clones, RRIM clones and clonal seedlings is exceptional in that all clones, including the Pil B84 control in the seedling trial, have been planted as budded stumps. The comparisons of the clones with their respective controls in the two clonal trials is valid, but the comparison of the seedlings with their control is affected because in all other seedling trials the control clone was budded in the field after its stock had been planted simultaneously with the clonal seedlings. The effect of this is to underestimate the adjusted girth of some of the clonal seedlings on coastal soil by a small but unknown amount. Consequently the superiority in growth of seedlings over clones on coastal soils may in fact be even greater than that already described. Furthermore if this bias is taken into account, clonal seedlings may grow slightly better on coastal sites than inland, but it is evident that the effect of soil type on seedlings would still not approach the corresponding effect on clones.

Variability. The variability between the members of each group (not to be confused with intra-family variability) is also summarised in Table 5. These variances between varieties of a group demonstrate that on coastal soils the clonal seedlings are significantly less variable in girth than the clones, and that on inland soils a similar conclusion is indicated but not established with confidence.

BROWN BAST

Direct comparisons of the mean incidence of brown bast in varieties cannot be made for the following reasons:

1. Observations have not been made for the same periods in the different trials.
2. The distribution of varieties in the trials is unbalanced.
3. Incidence has varied greatly from site to site.

Indirect comparison is possible, however, by comparing the mean incidence of each variety with that of the control clone Pil B84

present in the same trial since clone Pil B84 is present in all but one of the trials. The ratios obtained in this way can be compared if the assumption is made that there is no site/variety interaction.

Site Differences

Observations have shown no marked difference in the incidences of brown bast between inland and coastal sites. Incidence has been low to moderate on coastal, and low to high on inland sites. As there are fewer coastal sites, non-observation of high incidence on coastal sites cannot be taken to mean that brown bast incidence may not reach the same intensity there as it does on inland soils. Accordingly, for the purposes of comparing varietal incidence no distinction is made between coastal and inland sites.

TABLE 6. BROWN BAST INCIDENCE BY ESTATES

Annual mean number of trees out of production, expressed as percentage of the mature stand.

Estates	Old clones	RRIM clones	Clonal seedlings
(a) Inland			
R.R.I.E.S.	—	4	—
7	—	—	12
9	1	2	4
14	—	6	—
16	6	11	24
27	—	4	—
35	—	4	12
44	—	7	—
58	—	3	13
73	—	3	—
78	—	—	11
99	—	2	8
100	—	—	15
122	—	2	—
165	—	3	6
175	—	2	—
a/1	—	2	—
a/3	—	6	—
a/4	—	7	—
a/7	—	1	—
Mean, inland	3.5	4.1	11.7
(b) Coastal			
28	10	5	10
41	4	5	6
43	—	6	—
a/2	—	6	—
Mean, coastal	7.0	5.5	8.0

Table 6 gives the annual mean percentage of trees affected in each of the trials. From this Table it can be seen that the incidence of brown bast on some sites (e.g., 7, 16, 35, 58 and 100) is very much higher than on others, irrespective of the type of planting material considered. The reasons for this are not known.

Varietal Differences

No difference in the length of time from the commencement of tapping to the appearance of brown bast has been detected amongst varieties. The first cases of brown bast always appear in the first year of tapping. Varieties have tended to remain in the same rank throughout the period reviewed, whether the general level of incidence at a particular site is low, moderate or high.

The means of the ratios of the incidence of brown bast in each variety to that of the control clone Pil B84 are given in Tables 7, 8 and 9. The rank of each variety within groups and overall are also given in these Tables.

Table 10 shows the varieties divided into four classes: least susceptible, averagely susceptible, moderately susceptible and highly susceptible. The ratios for the varieties in the various classes of susceptibility are: least susceptible, below 0.8; averagely susceptible, between 0.8 and 1.2; moderately susceptible, between 1.3 and 1.7; highly susceptible, 1.8 and above. In this Table the least susceptible varieties are buddings of PB 86, Lun N and five RRIM clones. It is worth noting that Gl 1 which is known in practical planting to be highly susceptible to brown bast appears in the Table towards the upper limit of the moderately susceptible class. Two RRIM clones, 501 and 513, which are recommended for large scale planting, are classed as averagely susceptible.

All the clonal seedling families are classed either as moderately or highly susceptible, but only six of the 30 families under observation are classed as moderately susceptible.

TABLE 7. OLD CLONES, MEAN BROWN BAST INCIDENCE IN RELATION TO CONTROL PIL B84

Varieties arranged by rank within the group.

Varieties	No. of trials	Means of ratios to incidence in control	Overall rank
PB 86	4	0.5	1
Lun N	2	0.7	7
Pil B84	36	1.0	10
Tjir 1	5	1.4	26
Pil D65	4	1.5	30
PB 186	3	1.6	34
Tjir 16	3	1.6	34
Gl 1	4*	1.7	41
Rub 393	3	1.7	41
BD 5	3	1.7	41
Sab 24	3	1.8	47

All tapping S/2.d/2.100% except one trial* at S/3.d/2.67% from the 30th month of tapping

All the families of commercial importance are classed as highly susceptible.

A General Comparison of Clonal and Seedling Susceptibility

Table 11 gives a comparison of the incidence of brown bast in clones and seedlings where both types of planting material appear on the same estate. The figures show that the incidence of brown bast in the clonal seedlings is about double that in the clones.

Tapping System Adopted after the Widespread Appearance of Brown Bast in Certain Trials

In two clone trials certain clones were so badly affected with brown bast that their intensity of tapping had to be reduced. The tapping system on clones RRIM 500, 506, 512, 516 and 519 at the R.R.I. Experiment Station, and on clone Gl 1 at estate 41, was reduced from S/2.d/2.100% to S/3.d/2.67%. In spite of the reduction of tapping intensity new cases continued to appear in all of these clones. The rate of appearance of brown bast cases was reduced on the Experiment Station but the incidence of brown bast continued to increase in Gl 1 on estate 41.

In four clonal seedling trials brown bast incidence reached very serious proportions in all the families present. In two of these trials (Nos. 7 and 78) S/2.d/3.67% tapping was introduced and after this system had been in operation for 1½ years the proportion of trees affected fell from 26% and 22% respectively to 5% and a 'low' figure. Re-introduction of S/2.d/2.100% was followed by a recurrence of heavy incidence of brown bast. The figures were 14% and 11% respectively after one year and 18% in estate 78 after two years. On both these estates chronic brown bast cases had been thinned out just before the resumption of S/2.d/2.100% tapping. Thus the cases subsequently recorded were new ones.

In the seedling trial on estate 100, brown bast incidence rose to 13% after three years tapping on the S/2.d/2.100% system. The affected trees were thinned out, but by the end of the following year 26% of the remaining stand was affected. The S/2.d/2. 6m/9.67% tapping system was then introduced and for the following two years the incidence remained between 11 and 14%.

In the clonal seedling trial on estate 35, 20% of the stand was affected by brown bast by the time the first panel (20 in. height) had been tapped out, and 22% when the tapping of the second panel (30 in. height) was nearly completed. The trial had then been tapped for 4 years on the S/2.d/2.100% system. The rate of appearance of cases of brown bast suggested that it might be possible to keep

TABLE 8. RRIM CLONES, MEAN BROWN BAST INCIDENCE RELATIVE TO CONTROL, PIL B84

Varieties arranged by rank within group.

Varieties	No. of trials	Means of ratios to incidence in control	Overall rank
RRIM 195	2	0.5	1
514	11	0.5	1
5	2	0.6	4
107	3 †	0.6	4
505	10 †	0.6	4
508	4	0.9	8
517	3	0.9	8
27	1 †	1.0	10
503	6	1.0	10
513	10 *	1.0	10
516	5 §	1.0	10
518	10	1.0	10
519	11 § *	1.0	10
520	6	1.0	10
99	2 †	1.1	18
501	18 *	1.1	18
502	9 †	1.1	18
504	9	1.1	18
507	8	1.1	18
138	2 †	1.2	23
142	4 †	1.2	23
178	3	1.3	25
49	2 †	1.4	26
509	9 *	1.4	26
515	10	1.4	26
218	2	1.6	34
527	2	1.6	34
528	2	1.6	34
521	3	1.7	41
524	1	1.7	41
147	1	1.8	47
500	17 §	1.8	47
506	11 §	2.1	59
522	3	2.1	59
525	2	2.2	63
526	1	2.2	63
523	3	2.3	67
512	7 ‡	2.4	69
511	7	2.5	71
510	5 *	2.6	73
529	2 †	2.8	75

All tapping S/2.d/2.100% except:
§ one trial each at S/3.d/2.67% from 5th month of 3rd year of tapping.
‡ .. .. S/3.d/2.67% from 3rd month of 6th year of tapping.
† .. .. S/1.d/4.100%.
* .. .. V/2.d/2.100%.

TABLE 9. CLONAL SEEDLINGS, MEAN BROWN BAST INCIDENCE RELATIVE TO CONTROL PIL B84

Varieties arranged by rank within group.

Varieties	No. of trials	Means of ratios to incidence in control	Overall rank
Bukit Rajah	6 †	1.5	30
SR 9 illeg.	3	1.5	30
Sab 24 selfed	3	1.5	30
PB 25 selfed	1	1.6	34
RRIES Fd 2	3	1.6	34
RRIES Fd 22	3	1.7	41
St. Helier	1 ‡	1.8	47
PBISG 'D'	3 § ‡	1.8	47
PBISG 'E'	2 § ‡	1.8	47
PB 86 illeg.	2	1.8	47
RRIM 507 illeg.	1	1.8	47
Tjir 16 selfed	3	1.8	47
RRIES Fd 16N	5 † *	1.8	47
Gadek	3	1.9	57
BD 5 selfed	4	2.0	58
Buloh Akar	3	2.1	59
Rub 393 selfed	3	2.1	59
Chemara 'B'	1 §	2.2	63
PBISG 'C'	2 § ‡	2.2	63
Batu Kawan	10 § † *	2.3	67
Tjir 1 selfed	9 † *	2.4	69
RRIES Fd 15N	3	2.5	71
Labu	1 §	2.6	73
RRIES Fd 18	9 § † *	2.8	75
Sembrong (AVROS 163 illeg.)	1 §	2.8	75
Gl 1 selfed	5 *	2.9	78
RRIES Fd 4A	7 † *	2.9	78
PBISG 'CDE'	8 † *	3.0	80
Pilmoor duoclone	9 ‡ † *	3.0	80
RRIES Fd 14AB	9 § † *	3.1	82

All tapping S/2.d/2.100% except:

§ one trial at S/2.d/3.67% for a period during the 2nd and 3rd years and 5th and 6th years.

‡ one trial at S/2.d/3.67% for a period during the 2nd and 3rd years. This trial has PB 86 as control instead of Pil B84. PB 86 showed an incidence ratio of 0.5 to the control. Pil B84 (see Table 7). The ratio of incidence to the control has here been adjusted.

† one trial at S/2.d/2.6m/9.67% for a period during the 5th and 6th years.

* one trial at S/2.d/2.(2 × y/2)100% for 5th and 6th years.

TABLE 10. GRADING OF VARIETIES ACCORDING TO DEGREE OF SUSCEPTIBILITY TO BROWN BAST EXPRESSED AS RATIO TO CONTROL

Clones

Low	Average	Moderate	High
0.7 and under	0.8 – 1.2	1.3 – 1.7	1.8 and over
PB 86	Pil B84	Tjir 1	Sab 24
Lun N	RRIM 27	Tjir 16	RRIM 147
RRIM 5	RRIM 99	Pil D65	RRIM 500
107	138	PB 186	506
195	142	Gl 1	510
505	501	Rub 393	511
514	502	BD 5	512
	503	RRIM 49	522
	504	178	523
	507	218	525
	508	509	526
	513	515	529
	516	521	
	517	524	
	518	527	
	519	528	
	520		
Total 7	17	16	12

Clonal Seedling Families

		Bt. Rajah	PBISG 'C'	RRIM 507 illeg.
		SR 9 illeg.	PBISG 'D'	Tjir 1 selfed
		Sab 24 selfed	PBISG 'E'	Tjir 16 selfed
		PB 25 selfed	PBISG 'CDE', mixed	BD 5 selfed
		RRIES Fd 2	Chemara 'B'	Rub 393 selfed
		RRIES Fd 22	Pilmoor duoclone	Gl 1 selfed
			Labu	RRIES Fd 4A
			Gadek	RRIES Fd 14AB
			St. Helier	RRIES Fd 15N
			Buloh Akar	RRIES Fd 16N
			Batu Kawan	RRIES Fd 18
			Sembrong	
			PB 86 illeg.	
Total Nil	Nil	6	24	

TABLE 11. A COMPARISON OF BROWN BAST INCIDENCE IN CLONE AND SEEDLING TRIALS ON ESTATES HAVING TRIALS IN COMMON

Incidence quoted as mean annual % of mature stand totally dry. Mean (i) is for estates 9, 16, 28, 41. Mean (ii) is for all estates.

Planting material	Estate No.				Mean (i)	Estate No.				Mean (ii)
	9	16	28	41		35	58	99	165	
Old clones	1	6	10	4	5.2	—	—	—	—	5.2
RRIM clones	2	11	5	5	5.8	4	3	2	3	4.3
Clonal seedlings	4	24	10	6	11.0	12	13	8	6	10.4

the tapping system on 100% intensity by adopting a system whereby two S/2 panels were tapped alternatively year by year (tapping notation S/2.d/2.(2 × y/2).100%). The results were encouraging: 7% and 4% of the stand were affected at the end of the first and second years respectively. These results, however, may be influenced to some extent by the previous panel history.

Discussion on the Effects of Reduction of Tapping Intensity on Brown Bast Incidence.

From the figures above it is clear that neither S/3.d/2.67% nor S/2.d/2.6m/9.67% are effective systems of tapping for planting material which is susceptible to brown bast. It is probable that the frequency of tapping is too great and, in the S/2.d/2.6m/9.67% system, the period of rest is inadequate to compensate for the alternate daily tapping. The year's rest for each panel provided by the change-over system may be effective.

The only system to give conclusively beneficial results was the S/2.d/3.67%. The reduced frequency of tapping conforms with current views on brown bast control. An additional advantage is the reduction of tapping costs. On the other hand, a 33% reduction in tapping intensity (100% to 67%) may lead to a 20% reduction of the yield from the surrounding trees which are not affected by brown bast and could be tapped at 100% intensity.

VIRGIN BARK THICKNESS AND FIRST RENEWAL

Bark thickness measurements have been recorded by the Schlieper gauge. Virgin bark thickness was taken at about 4 in. above the panel. The thickness of renewed bark was taken at the appropriate height on the tapping panel, this being reckoned by means of the monthly bark consumption marks, i.e., where the tapping cut was 1, 2, 3, etc. years previously.

A General Comparison Between Clone and Clonal Seedling Bark Thickness

A summary of the mean clonal and clonal seedling bark thicknesses is given in Table 12. Since the inland and coastal means are obtained from a large number of varieties, though not necessarily the same ones throughout, they have been combined with equal weight to give the clonal and seedling means in the upper section of the Table.

Virgin bark. Mean virgin bark thicknesses are 10.0 mm and 9.9 mm respectively for clones and seedling families. These are the means of many varieties (47 clones, 26 seedling families) represented over eighteen estates; thus this comparison of clonal bark thickness with seedling bark thickness for rubber of about 10 - 14 years old may be accepted as being representative. There is in general little difference between the virgin bark thicknesses of budgrafted and clonal

TABLE 12. COMPARATIVE BARK THICKNESS MEASUREMENTS, IN MILLIMETRES

VB = Mean thickness of virgin bark. RB 1, 2, 3, etc. = mean thickness of renewed bark of 1, 2, 3, etc. years of growth.
% = renewed bark as a percentage of virgin bark thickness.

Planting material and soil type	No. of varieties recorded	VB	RB 1		RB 2		RB 3		RB 4		RB 5		RB 6		RB 7	
		mm	mm	%	mm	%	mm	%	mm	%	mm	%	mm	%	mm	%
Clones																
Old: inland	10	10.8	6.1	56	7.0	65	7.4	69	8.0	74	8.4	78	8.8	81	9.4 (11.0)	85
coastal	11	9.3	5.5	59	6.2	67	6.6	71	7.0	75	7.3	78	7.3	78	7.9 (9.9)	80
New: inland	36	10.0	5.5	55	5.9	59	6.4	64	7.1	71	8.4	74	7.8	78	7.9 (10.2)	77
coastal	20	9.9	5.7	58	6.2	63	6.7	68	6.7	68	7.0	71	7.4	75	7.8 (10.0)	78
Clonal seedlings																
Inland	24	10.2	5.8	57	6.3	62	7.3	72	7.7	75	8.1	79	8.1 (10.4)	78	8.5 (10.4)	82
Coastal	21	9.6	6.1	64	6.7	70	7.3	76	7.5	78	8.0	83	7.6	79	7.7	80
Mean																
Clones		10.0	5.7	57	6.3	63	6.8	68	7.2	72	7.8	78	7.8	78	8.2 (10.3)	80
Seedlings		9.9	6.0	61	6.5	66	7.3	74	7.6	77	8.0	81	7.8 (10.0)	78	8.1 (10.0)	78
Inland																
Old clones	10	10.8	6.1	56	7.0	65	7.4	69	8.0	74	8.4	78	8.8	81	—	—
RRIM clones	20	10.7	5.8	54	6.3	59	6.6	62	7.0	65	7.6	71	8.1	76	8.2 (10.6)	77
Cl. seedlings	19	10.3	5.8	56	6.3	61	7.3	71	7.7	75	8.1	79	8.1 (10.4)	78	8.4 (10.4)	81
Coastal																
Old clones	10	9.3	5.6	60	6.2	67	6.6	71	7.0	75	7.3	78	7.4	80	—	—
RRIM clones	20	9.9	5.7	58	6.2	63	6.7	68	6.7	68	7.0	71	7.4	75	7.8 (10.0)	78
Cl. seedlings	19	9.6	6.1	64	6.7	70	7.3	76	7.5	78	7.9	82	7.7	80	7.7	80
Mean																
Inland		10.6	5.9	56	6.5	61	7.1	67	7.6	72	8.0	75	8.3	78	8.3 (10.5)	79
Coastal		9.6	5.8	60	6.4	67	6.9	72	7.1	74	7.7	80	7.5	78	7.8	81

Note. Virgin bark thickness quoted in the column headed VB is relevant to RB thickness throughout except where a different figure for virgin bark is quoted in brackets. In such instances VB and RB are recorded from a smaller number of estates.

seedling trees when grown under similar conditions.

Renewed bark. Renewal can be expressed either as thickness in millimeters or as a percentage of the thickness of the virgin bark. In practice the physical thickness is the more important, since it is this which is tapped on second or subsequent cycles of tapping. Both measures are given in the tabulation of data (Tables 14, 15 and 16), and it is shown there that material with thick virgin bark tends to have thick renewal and often a low percentage. Conversely material with thin virgin bark tends towards thin renewal but frequently to a high percentage. The use of percentage as a measure of renewal may thus be misleading.

Clonal seedlings started with better renewal than clones and maintained this position for the first four years, after which their rate of renewal slowed down. The rate of renewal of the clones continued so that after six years' renewal the average thickness was the same (7.8 mm) for both classes of material; after seven years, renewal of the budgrafts was actually slightly better than that of the seedlings—8.2 mm and 8.1 mm respectively. Such a difference is small and may not be significant. Under the conditions of good maintenance and a high standard of tapping pertaining in these trials, the renewal of bark in clones and seedlings after five years is approximately equal.

The thicknesses recorded in Table 12 indicate that renewal had not ceased in either group by the seventh year; it might in fact continue further to a lesser degree.

A Comparison of Bark Thickness on Inland and Coastal Soils

The data in Table 12 (upper half), though showing records from inland and coastal areas separately, have been drawn from all the recordings made. A similar summary has been prepared in the lower half of the Table for the varieties planted on both inland and coastal soils, so that differences which might arise through presence or absence of any particular varieties in either group are eliminated.

Virgin bark. Inland areas produced thicker virgin bark (by about 10%), 10.6 mm against 9.6 mm. This has been so for both clone and seedling families. It is usual within a variety grown in any particular locality to find that the larger trees have the thicker bark and that there is a parallel relationship between girth and bark thickness. Between localities, and thus between coastal clays and inland soils, this relationship breaks down.

Renewed bark. At first, renewal was slightly better on the inland areas than on the coastal (5.9 mm against 5.8 mm) and this small difference was progressively increased to 0.8 mm (8.3 mm against 7.5 mm) after six years. The means for seven years' renewal, though based on incomplete data, also show an appreciable extra thickness of bark on inland soils.

The superiority of renewal by inland-grown rubber over that on coastal soils tended to increase progressively each year till by the sixth year it had reached the same relative superiority shown by its virgin bark.

Table 13 shows that the inland virgin bark had an apparent superiority of 10.4% over the coastal bark and that its superiority of renewal built up from 1.7% after one year to 10.7% after six. It suggests that in general (varietal differences excepted) thick virgin bark is the precursor of thick renewal and that differences of thickness in virgin bark are likely to be reflected in the renewed bark.

Bark Characteristics of Varieties

Among the old clones (Table 14) satisfactory renewal is recorded for Sab 24, Tjir 16, Rub 393 and PB 186 on inland soils, and on coastal soils for the same clones, excepting Rub 393 and including Gl 1 and BD 5. Tjir 1 is disappointing on both inland and coastal soils; that PB 86 is near the bottom of each list is not altogether unexpected.

Of the new clones (Table 15) on inland soil, RRIM 142, 500, 502, 503, 505, 506, 507, 508, 510, 511, 512, 513, 515, 516, 519, 520, 527 and 528 have given renewal above the group mean, but in particular RRIM 502, 503, 505, 515 and 516 appear outstanding for

TABLE 13. RELATIVE THICKNESS OF VIRGIN AND RENEWED BARK ON INLAND AND COASTAL SOILS

*VB = thickness of virgin bark in mm. RB 1 - 6 = thickness of renewed bark of 1 - 6 years growth in mm.**

Soil type	VB	RB 1	RB 2	RB 3	RB 4	RB 5	RB 6
Inland (I)	10.6	5.9	6.5	7.1	7.6	8.0	8.3
Coastal (C)	9.6	5.8	6.4	6.9	7.1	7.7	7.5
I as % of C	110.4	101.7	101.6	102.9	107.0	103.9	110.7

* Data for 7 years' renewal are omitted as they are incomplete.

consistency, RRIM 142, 513, 520 and 528 appear to be fairly satisfactory. On coastal soils RRIM 502, 503, 505, 507, 508, 509, 510, 512, 515 and 520 are above the mean, but RRIM 502, 507 and 508 are outstanding. It will be noted that these clones also ranked high on the inland soils. RRIM 505, 509, 510 and 520 show a fair performance and RRIM 503, 512 and 515 show a decline with the passage of time.

Among clones currently recommended for planting (R.R.I.M. 1955), RRIM 501 maintains a steady position of mediocrity on inland soils and an inferior position on coastal; RRIM 513, already noted above, is just over the mean on inland and under it on coastal soils. RRIM 526 and 527 are unfortunately not tested on coastal soils in this series of trials; the performance of the latter on inland soils has already been noted, the performance of the former is poor. It is perhaps worth mentioning one other clone, RRIM 107, which has been planted commercially and whose renewal has been poor.

Clonal seedling families (Table 16) with bark renewal above the mean on inland soils have been BD 5 selfed, Gl 1 selfed, Rub 393 selfed, PB 25 selfed, RRIES Fd 15N, Sab 24 selfed, Buloh Akar, Tjir 1 selfed, Tjir 16 selfed and SR 9 selfed. Of these the first three have remained consistently at the top of the group. PB 25 selfed, RRIES Fd 15N, Sab 24 selfed, Tjir 1 selfed and SR 9 have all shown improvement in grading, while Buloh Akar and Tjir 16 selfed have tended to decline.

On coastal soils good renewal has been made by Rub 393 selfed, Buloh Akar, Gl 1 selfed, RRIES Fd 16N, Tjir 16 selfed, RRIES Fd 22 and Batu Kawan, and fair renewal by PB 86 illegitimate and SR 9 illegitimate. Though ranked high, Sab 24 selfed showed a definite decline, as did RRIM 507 illegitimate.

Amongst the families which have been planted extensively on a commercial scale, PBISG 'CDE' and Pilmoor duoclone seedlings have ranked low on both inland and coastal soils. Tjir 1 selfed ranks just below the mean on coastal soils and, as just noted above, rather better on inland soils. Gadek seedlings fell just below the mean on both. PB 86 illegitimate is not recorded on inland soils, and is graded just above the mean on coastal soils.

YIELD

Amalgamation of Yield Records

In most of the trials, yields are available during the first five years of tapping. Details of these records and their separate trial analyses are too numerous to present here, but summaries are given in Tables 17 to 21 for each variety by unweighted averaging over its various trials. For example, Table 17 lists separately for trials on inland and coastal sites the mean yields (lb per acre per annum) averaged over five years of nine old clones. The clones are listed in order of observed mean yields, and the varying number of trials contributing to these means are also quoted

TABLE 14. BARK THICKNESS (VIRGIN AND RENEWED) OLD CLONES

Clones are ranked in descending order of virgin bark thickness. Ranks in bold print indicate bark thickness equal to or thinner than the mean for the group. VB = Virgin bark. RB 1-6 = Renewed bark of 1-6 years growth.

Inland								
Clones	Ranking on bark thickness							Ranking on %
	VB	RB1	RB2	RB3	RB4	RB5	RB6	RB6
PB 186	**1**	5	4	5	**5**	4	4	10
Sab 24	2	2	3	2	2	1	1	1
Tjir 16	2	1	1	1	1	2	2	2
Rub 393	4	3	2	3	3	3	3	2
BD 5	**5**	7	6	7	8	5	5	7
Pil B84	6	6	7	6	6	5	5	4
Tjir 1	7	4	5	4	4	5	7	5
Gl 1	7	10	9	10	7	8	8	6
Pil D65	9	9	9	9	10	10	10	9
PB 86	10	7	8	7	9	9	9	7
Max. mm	12.5	7.3	8.4	9.0	9.2	9.8	10.1	
Mean mm	10.8	6.1	7.0	7.4	8.0	8.4	8.8	
Min. mm	9.8	4.8	5.8	6.2	6.7	7.4	7.7	

Coastal								
Clones	Ranking on bark thickness							Ranking on %
	VB	RB1	RB2	RB3	RB4	RB5	RB6	RB6
PB 186	1	3	1	6	3	6	2	8
Lun N	2	9	**10**	1*	1*	9	7	11
Gl 1	3	**11**	**10**	4	3	5	4	5
Tjir 1	4	2	4	6	3	2	6	9
Sab 24	5	4	3	3	1	1	1	3
Tjir 16	6	1	2	1	3	2	5	5
Pil B84	7	5	5	10	10	10	11	9
Pil D65	8	7	7	11	11	11	10	5
BD 5	8	7	7	4	3	2	2	1
Rub 393	10	5	7	8	8	7	7	4
PB 86	11	10	5	9	9	8	7	2
Max. mm	10.2	6.6	6.6	7.0	7.4	8.0	8.0	
Mean mm	9.3	5.5	6.2	6.6	7.0	7.3	7.3	
Min. mm	8.4	5.0	5.6	6.0	6.3	6.7	6.8	

* Unusually high renewal recorded on one estate; cause unknown.

TABLE 15. BARK THICKNESS (VIRGIN AND RENEWED) RRIM CLONES

Clones are ranked in descending order of virgin bark thickness. Ranks in bold print indicate bark thickness equal to or thinner than the mean for the group. VB = Virgin bark. RB 1-6 = Renewed bark 1-6 years growth.

Inland

Clones	Ranking on bark thickness							Ranking on %
	VB	RB1	RB2	RB3	RB4	RB5	RB6	RB6
RRIM 505	**1**	**1**	**1**	**1**	2	**1**	**1**	24
508	2	8	6	8	8	7	5	34
503	3	8	6	11	8	7	8	27
516	3	3	2	4	5	9	2	21
511	5	4	5	6	14	**17**	12	30
520	6	14	14	13	**19**	14	16	35
507	7	12	10	8	8	5	6	19
502	8	14	6	11	15	9	10	24
504	9	8	10	13	**25**	**19**	**19**	27
515	9	4	4	4	7	3	4	7
500	11	6	6	8	15	9	10	19
509	12	**25**	**26**	**30**	**27**	**25**	**26**	35
519	12	**24**	17	18	**17**	**19**	9	15
512	14	2	2	3	4	4	6	6
147	15	**27**	**29**	**26**	**17**	**19**	**23**	27
501	15	**21**	**21**	**23**	**27**	**27**	**24**	30
510	17	12	14	13	**19**	15	15	16
506	**18**	8	10	**19**	**21**	12	13	13
517	**18**	6	13	13	**27**	14	**22**	26
513	**20**	**21**	**19**	**19**	**23**	**17**	17	16
528	**20**	14	**19**	2	3	5*	13*	11
527	**22**	14	18	6	1	2	2	1
522	**23**	**20**	**24**	**26**	**25**	**33**	**34**	30
518	**24**	**23**	**21**	**25**	**33**	**28**	**26**	21
521	**25**	14	**23**	**26**	**33**	**33**	**31**	23
524	**26**	**32**	**32**	**19**	**25**	**28**	**20**	16
107	**27**	**36**	**35**	**35**	8	**25**	**20**	5
195	**28**	**35**	**35**	**36**	8	**19**	**28**	13
218	**29**	**31**	**33**	**33**	**24**	**28**	**28**	7
525	**29**	**25**	**26**	13	**21**	**23**	**28**	7
142	**31**	**32**	**30**	**32**	5	12	17	2
514	**31**	14	14	**22**	**31**	**32**	**31**	11
178	**33**	**27**	**30**	**30**	8	**23**	**24**	3
523	**34**	**32**	**33**	**33**	**36**	**36**	**36**	30
526	**35**	**27**	**26**	**23**	**27**	**31**	**33**	3
529	**35**	**30**	**25**	**29**	**32**	**33**	35	7
Max. mm	12.8	7.0	7.6	7.8	9.2	9.1	9.7	
Mean mm	10.0	5.5	5.9	6.4	7.1	7.4	7.8	
Min. mm	7.7	4.2	4.6	5.0	5.8	5.8	5.8	

Coastal

Clones	Ranking on bark thickness							Ranking on %
	VB	RB1	RB2	RB3	RB4	RB5	RB6	RB6
RRIM 508	**1**	2	4	**1**	3	**1**	**1**	13
505	2	5	2	3	2	2	6	15
520	2	2	8	8	5	2	4	13
502	4	7	6	7	7	7	2	5
503	4	4	2	2	5	5	6	11
507	6	8	6	4	3	2	2	3
509	7	**10**	**10**	8	**10**	10	10	15
515	8	5	5	6	9	9	9	9
512	9	1	1	4	1	5	4	1
510	10	8	9	8	8	8	8	1
500	**11**	**12**	**12**	**12**	**12**	**12**	**13**	17
522	**11**	**15**	**13**	**14**	**18**	**16**	**18**	19
511	**13**	**10**	**10**	**11**	**10**	**11**	**11**	5
501	**14**	**20**	**20**	**19**	**20**	**19**	**19**	20
519	**15**	**16**	**17**	**13**	**13**	**13**	**12**	9
504	**16**	**13**	**13**	**14**	**15**	**14**	**14**	17
506	**17**	**13**	**15**	**14**	**14**	**14**	**14**	11
513	**18**	**16**	**15**	**14**	**15**	**16**	**14**	7
518	**18**	**16**	**18**	**18**	**15**	**18**	**14**	7
514	**20**	**16**	**18**	**19**	**18**	**19**	**20**	3
Max. mm	12.5	6.4	7.7	8.2	7.8	8.2	9.1	
Mean mm	9.9	5.7	6.2	6.7	6.7	7.0	7.4	
Min. mm	7.6	4.8	5.2	5.6	5.7	5.8	6.0	

* Renewal excellent to 4th year after which it ceased.

TABLE 16. BARK THICKNESS (VIRGIN AND RENEWED) OF CLONAL SEEDLING FAMILIES AND BUDDED CONTROL

Varieties are ranked in descending order of virgin bark thickness. Ranks in bold print indicate bark thickness equal to or thinner than the mean for the group. VB = Virgin bark. RB 1-7 = Renewed bark of 1-7 years growth.

Inland

Families	Ranking on bark thickness						Ranking on %
	VB	RB1	RB2	RB3	RB4	RB5	RB5
BD 5	1	2	3	1	1	1	1
Gl 1	2	1	1	5	3	2	4
Rub 393	2	3	3	2	2	3	10
PB 25	4	**12**	**12**	8	9	4	10
RRIES Fd 15N	5	7	7	8	6	4	9
RRIES Fd 18	5	9	9	**11**	**11**	**12**	24
Sab 24	7	**12**	9	8	**13**	8	13
B. Kawan	8	**19**	**14**	**17**	**17**	**12**	19
Pilmoor	8	7	**18**	**15**	**13**	**10**	13
Buloh Akar	8	4	5	2	6	8	10
Tjir 1	8	**9**	**11**	5	8	6	6
RRIES Fd 14AB	8	**9**	**14**	**13**	**13**	**10**	13
PBISG 'CDE'	13	**21**	**21**	**15**	**16**	**16**	19
RRIES Fd 22	13	6	7	5	3	**12**	13
Tjir 16	**15**	4	1	2	3	6	5
RRIES Fd 2	**15**	**12**	**12**	**20**	**20**	**19**	21
Pil B84 budded	**17**	**21**	**18**	**22**	**11**	**16**	13
SR 9	**18**	**21**	**21**	**17**	**20**	**21**	21
RRIES Fd 16N	**18**	**15**	**24**	**20**	**17**	**24**	24
Gadek	**20**	**15**	**14**	**11**	10	**12**	6
Bt. Rajah	**21**	**25**	**25**	**22**	**23**	**25**	21
RRIES Fd 4A	**21**	**15**	**21**	**17**	**23**	**21**	13
Chemara 'B'	**23**	**15**	5	**24**	**25**	**16**	6
Labu	**24**	**21**	**14**	**13**	**17**	**19**	1
Sembrong	**25**	**19**	**18**	**25**	**20**	**21**	1
Max. mm	11.0	6.6	7.0	8.1	8.5	9.2	
Mean mm	10.2	5.8	6.3	7.3	7.7	8.1	
Min. mm	9.0	5.0	5.7	6.6	7.1	7.4	

Coastal

Families	Ranking on bark thickness								Ranking on %
	VB	RB1	RB2	RB3	RB4	RB5	RB6	RB7	RB7
Rub 393	1	1	1	3	1	1	1	1	8
RRIES Fd 16N	2	6	5	9	6	3	4	4	15
Gl 1	3	5	5	1	2	5	3	3	8
RRIES Fd 22	3	9	8	5	5	5	7	6	15
Buloh Akar	5	7	2	4	4	3	2	2	3
Sab 24	6	2	4	5	6	2	4	6	13
PB 86	6	10	8	8	11	**10**	**13**	9	21
RRIM 507	8	2	5	9	6	5	**15**	**11**	18
Tjir 16	9	2	2	1	3	5	4	4	1
RRIES Fd 2	9	8	11	11	10	**10**	**16**	**16**	22
SR 9	**11**	**13**	**12**	**13**	**14**	**16**	**13**	8	6
Gadek	**12**	**11**	10	5	9	9	**9**	**11**	8
B. Kawan	**13**	**15**	**19**	**16**	**17**	**10**	8	9	3
RRIES Fd 18	**13**	**17**	16	16	17	14	9	**13**	8
BD 5	**15**	**20**	**15**	**14**	**15**	**14**	**9**	**13**	6
PBISG 'CDE'	**16**	**15**	**16**	**16**	**17**	**17**	**19**	**18**	18
Tjir 1	**16**	**13**	**13**	**12**	**12**	**10**	**9**	**13**	3
RRIES Fd 14AB	**18**	**12**	**13**	**14**	**16**	**17**	**17**	**18**	13
Pil B84 budded	**19**	**17**	**16**	**16**	**12**	**19**	**17**	**16**	1
RRIES Fd 4A	**20**	**17**	**19**	**16**	**20**	**21**	**21**	**21**	18
Bt. Rajah	**21**	**21**	**21**	**21**	**20**	**19**	**20**	**20**	8
Pilmoor	**22**	**22**	**22**	**22**	**22**	**22**	**22**	**22**	15
Max. mm	10.8	7.0	7.8	8.4	8.8	8.8	8.7	8.7	
Mean mm	9.6	6.1	6.7	7.3	7.5	8.0	7.6	7.7	
Min. mm	8.1	4.9	5.5	5.6	5.8	6.4	6.5	6.4	

TABLE 17. OLD CLONES: MEAN YIELDS (LB PER ACRE PER ANNUM)

Number of trials shown in parenthesis in third column

Rank of mean yield	Clone	Mean yield over 5 years (lb/ac./annum)	s.e. of mean from inter-estate variances (lb/ac./annum)	s.e. of mean from intra-estate variances (lb/ac./annum)	Rank of mean yields: year				
					1	2	3	4	5
(a) *Inland estate trials* *									
1	Tjir 16	1099 (2)	± 41	± 22	—	1	1	1	1
2	PB 86	977 (2)	71	24	—	2	2	3	3
3	Tjir 1	932 (2)	36	24	—	4	3	2	4
4	Rub 393	856 (1)	—	30	—	6	5	4	2
5	Gl 1	825 (2)	9	23	—	3	4	7	6
6	Pil B84	754 (2)	61	24	—	5	6	6	7
7	Lun N	753 (1)	—	30	—	8	7	5	8
8	Pil D65	708 (2)	61	24	—	7	8	8	9
9	BD 5	598 (1)	—	30	—	9	9	9	5
(b) *Coastal estate trials*									
1	Gl 1	1223 (2)	± 209	± 16	1	1	4	7	2
2	PB 86	1162 (2)	188	16	3	2	1	2	3
3	Lun N	1156 (2)	66	23	2	8	6	1	1
4	Sab 24	1092 (2)	174	26	6	3	2	3	4
5	Tjir 1	1044 (2)	70	26	4	4	3	4	9
6	Tjir 16	1001 (2)	253	26	5	6	5	6	7
7	Pil B84	920 (4)	91	16	7	10	9	5	6
8	PB 186	901 (2)	204	16	9	9	7	9	5
9	Rub 393	885 (2)	142	26	10	5	10	8	8
10	Pil D65	837 (2)	134	16	8	7	8	10	10
11	BD 5	677 (2)	157	16	11	11	11	11	11

* Information on yields during the first year is not available for Gl 1, BD 5, Rub 393, Lun N. Their mean yields are calculated over 4 years and all rankings have been omitted for the first year.

TABLE 18. CLONAL SEEDLINGS: MEAN YIELDS (LB PER ACRE PER ANNUM)

Number of trials shown in parenthesis in third column

(a) Inland estates

Rank of mean yield	Clonal seedling	Mean yield over 5 years (lb/ac./annum)	s.e. of mean from inter-estate variances (lb/ac./annum)	s.e. of mean from intra-estate variances (lb/ac./annum)	Mean % of control (Pil B84)	Rank of mean % of control	Rank of mean yields: year				
							1	2	3	4	5
1	PBISG 'CDE'	1233 (5)	± 130	± 19	154	2	1	1	1	12	3
2	Tjir 1 selfed	1203 (6)	87	16	152	3	3	3	2	7	2
3	RRIES Fd 15N	1196 (2)	40	35	126	11	2	2	5	5	13
4	RRIES Fd 18	1132 (6)	64	16	137	4	11	5	3	9	11
5	Sembrong	1129 (1)	—	30	117	21	7	9	21	1	17
6	Bukit Rajah mixed	1120 (4)	78	21	120	13	6	4	4	15	20
7	RRIES Fd 14AB	1114 (6)	75	16	135	5	5	6	9	10	6
8	PBISG 'E'	1112 (2)	2	17	115	23	12	20	10	3	7
9	Batu Kawan	1100 (7)	66	15	133	6	10	8	8	13	8
10	PBISG 'C'	1090 (2)	16	25	114	24	13	18	16	4	9
11	Chemara 'B'	1073 (1)	—	30	117	20	15	13	23	2	16
12	RRIES Fd 16N	1060 (4)	106	17	131	10	8	10	13	21	5
13	Pilmoor	1049 (7)	76	14	133	7	9	14	12	19	10
14	Gadek mixed	1042 (2)	198	35	132	9	18	7	6	18	14
15	Labu	1039 (1)	—	30	107	27	14	11	22	6	21
16	Gl 1 selfed	1031 (3)	115	26	158	1	20	17	11	17	1
17	PBISG 'D'	1022 (3)	15	15	116	22	16	27	19	8	12
18	PB 86 budded	1018 (1)	—	17	—	—	4	29	25	11	15
19	RRIES Fd 4A	997 (4)	95	22	132	8	19	12	15	23	19
20	PB 25 selfed	987 (1)	–	63	120	14	21	15	7	22	26
21	RRIES Fd 2	967 (2)	106	35	123	12	25	23	14	16	25
22	St. Helier	959 (1)	—	17	—	—	17	31	30	14	4
23	Rub 393 selfed	938 (2)	136	35	119	16	26	16	18	24	28
24	RRIES Fd 22	930 (2)	112	25	118	18	24	24	20	25	22
25	Sab 24 selfed	925 (2)	10	35	118	17	23	21	17	26	30
26	Buloh Akar	918 (2)	60	35	117	19	22	19	26	28	24
27	PB 86 illeg.	894 (1)	—	29	120	15	27	25	28	27	23
28	SR 9 illeg.	870 (2)	92	35	111	26	28	22	27	31	29
29	Tjir 16 selfed	868 (2)	78	35	111	25	29	26	24	30	27
30	Pil B84 budded	863 (7)	79	15	100	29	30	30	31	20	18
31	BD 5 selfed	829 (2)	62	35	106	28	31	28	29	29	31

Note : The above list includes 29 clonal seedlings and also two clones, Pil B84 and PB 86, which appeared in the clonal seedling trials as controls.

TABLE 18 (Continued). CLONAL SEEDLINGS: MEAN YIELDS (LB PER ACRE PER ANNUM)

Number of trials shown in parenthesis in third column

(b) Coastal estates

Rank of mean yield	Clonal seedling	Mean yield over 5 years (lb/ac./annum)	s.e. of mean from inter-estate variances (lb/ac./annum)	s.e. of mean from intra-estate variances (lb/ac./annum)	Mean % of control (Pil B84)	Rank of mean % of control	Rank of mean yields: year				
							1	2	3	4	5
1	PBISG 'CDE'	988 (2)	± 62	± 25	140	1	6	6	1	1	2
2	RRIM 507 illeg.	960 (1)	—	37	112	9	1	1	3	7	7
3	Tjir 1 selfed	942 (2)	143	25	131	3	9	8	9	2	1
4	Batu Kawan	929 (2)	32	25	133	2	7	2	4	4	6
5	RRIES Fd 22	927 (1)	—	37	108	10	2	3	10	3	8
6	Sab 24	907 (1)	—	37	106	11	11	12	7	8	3
7	Gadek mixed	906 (1)	—	37	105	15	3	5	2	9	16
8	RRIES Fd 18	904 (2)	113	25	127	4	4	4	6	5	11
9	Rub 393 selfed	902 (1)	—	37	105	14	8	16	5	6	4
10	PB 86 illeg.	901 (1)	—	37	105	13	10	7	8	10	5
11	Buloh Akar mixed	831 (1)	—	37	97	17	5	10	18	11	18
12	SR 9 illeg.	827 (1)	—	37	96	19	12	13	15	16	13
13	Bukit Rajah mixed	824 (2)	30	25	119	6	18	14	14	12	10
14	Gl 1 selfed	822 (1)	—	37	96	18	14	11	11	17	17
15	Tjir 16 selfed	820 (1)	—	37	95	20	13	9	12	20	14
16	BD 5 selfed	819 (2)	106	25	115	7	16	17	17	13	9
17	RRIES Fd 14AB	806 (2)	77	25	114	8	17	18	13	15	15
18	RRIES Fd 2	797 (1)	—	37	93	21	15	15	16	14	19
19	Pilmoor	740 (1)	—	34	126	5	20	20	20	18	21
20	RRIES Fd 4A	736 (2)	31	25	105	12	21	21	19	19	20
21	Pil B84 budded	723 (2)	136	25	100	16	22	22	21	21	12
22	RRIES Fd 16N	713 (1)	—	37	83	22	19	19	22	22	22

TABLE 19. RRIM 500 SERIES: MEAN YIELDS (LB PER ACRE PER ANNUM)

Number of trials shown in parenthesis in third column

(a) *Inland estates*

Rank of mean yield	Clone	Mean yield over 5 years (lb/acre/annum)	s.e. of mean from inter-estate variances (lb/acre/annum)	s.e. of mean from intra-estate variances (lb/acre/annum)	Mean % of control (Pil B84)	Rank of mean % of control	Rank of mean yields: year				
							1	2	3	4	5
1	RRIM 501	1485 (11)	± 103	± 17	142	6	8	3	4	3	3
2	511	1481 (3)	263	31	129	11	13	7	2	1	7
3	513	1471 (5)	178	32	151	4	3	1	6	4	5
4	503	1455 (4)	90	31	147	5	1	2	8	12	9
5	520	1441 (4)	78	36	152	2	5	6	9	5	4
6	527	1418 (2)	121	32	157	1	24	15	3	7	2
7	522	1384 (1)	—	100	136	9	11	11	15	2	16
8	509	1382 (5)	129	27	137	8	4	4	5	16	14
9	516	1368 (5)	114	29	133	10	6	8	10	8	19
10	526	1366 (1)	—	44	152	3	25	23	1	9	1
11	508	1339 (3)	232	36	126	13	14	5	7	13	6
12	502	1288 (6)	111	24	140	7	7	14	16	19	13
13	521	1273 (3)	117	44	128	12	10	10	14	18	18
14	506	1255 (6)	85	24	114	23	2	9	20	21	36
15	512	1254 (5)	89	25	117	21	12	12	19	10	25
16	500	1253 (10)	73	17	122	15	16	16	12	11	20
17	514	1246 (7)	101	24	122	17	19	18	11	15	11
18	519	1238 (7)	124	24	125	14	17	19	23	6	15
19	510	1178 (3)	100	36	111	27	9	13	18	27	33
20	504	1167 (6)	154	24	108	31	18	17	17	14	30
21	507	1164 (6)	79	24	114	22	15	21	22	17	22
22	518	1063 (7)	79	25	107	33	21	22	26	22	32
23	525	1052 (2)	6	38	119	19	28	29	25	24	12
24	524	1023 (1)	—	44	114	24	31	34	21	25	10
25	515	1014 (6)	94	28	110	28	23	24	30	26	24
26	Pil B84	999 (15)	44	15	100	34	27	27	28	23	31
27	RRIM 523	997 (3)	67	23	121	18	26	25	32	28	26
28	147	996 (1)	—	46	109	30	20	20	27	37	40
29	529	988 (1)	—	44	110	29	29	33	13	30	23
30	517	967 (3)	74	40	91	39	32	28	24	20	34
31	505	966 (6)	63	23	92	38	22	26	29	33	35
32	138	948 (1)	—	63	108	32	37	37	31	31	8
33	107	937 (2)	83	30	122	16	30	31	35	32	27
34	5	911 (2)	187	37	119	20	35	38	34	29	17
35	142	901 (3)	85	29	111	26	33	32	36	35	21
36	195	896 (2)	47	39	100	35	38	30	33	34	29
37	218	808 (2)	18	39	90	40	40	39	37	36	28
38	178	793 (3)	36	29	99	37	34	35	38	38	37
39	49	738 (1)	—	40	114	25	36	36	40	40	38
40	99	651 (1)	—	40	100	36	39	40	41	41	39
41	528	583 (2)	71	38	66	41	41	41	39	39	41

TABLE 19 (Continued). RRIM 500 SERIES: MEAN YIELDS (LB PER ACRE PER ANNUM)

Number of trials shown in parenthesis in third column

(b) *Coastal estates*

Rank of mean yield	Clone	Mean yield over 5 years (lb/acre/annum)	s.e. of mean from inter-estate variances (lb/acre/annum)	s.e. of mean from intra-estate variances (lb/acre/annum)	Mean % of control (Pil B84)	Rank of mean % of control	Rank of mean yields: year				
							1	2	3	4	5
1	RRIM 501	1421 (4)	± 130	± 17	167	1	5	4	1	2	1
2	513	1345 (3)	188	22	155	2	10	8	2	1	2
3	500	1201 (4)	114	17	141	4	6	15	4	3	3
4	509	1190 (1)	—	42	141	5	2	1	6	8	18
5	508	1182 (1)	—	42	141	6	14	6	5	4	8
6	504	1158 (3)	153	22	134	9	7	11	3	6	14
7	502	1158 (1)	—	42	138	7	3	3	14	11	7
8	510	1135 (1)	—	42	135	8	4	5	11	19	9
9	519	1117 (2)	160	25	149	3	16	9	8	9	4
10	503	1101 (1)	—	42	131	11	1	2	19	16	20
11	512	1095 (1)	—	42	130	12	8	7	17	21	5
12	507	1071 (2)	62	22	128	13	17	16	13	7	6
13	506	1058 (4)	72	17	126	14	9	14	9	10	13
14	515	1040 (2)	10	23	125	15	11	13	12	12	10
15	514	1037 (4)	134	17	120	17	18	18	7	5	11
16	511	1028 (3)	100	18	132	10	12	12	10	13	16
17	520	1026 (1)	—	42	122	16	15	10	16	14	15
18	522	954 (2)	74	23	114	18	13	19	18	18	12
19	505	911 (2)	51	23	109	19	19	17	15	15	19
20	Pil B84	858 (4)	92	17	100	21	20	21	20	17	17
21	RRIM 518	788 (3)	22	18	103	20	21	20	21	20	21

(a similar summary of results on coastal sites is given in the same Table). Tables 18 and 19 deal with the RRIM clones and the clonal seedlings on inland and coastal sites.

Control clone Pil B84 has been tested in most trials and the 5-year mean yield of a clone or clonal seedling can be expressed as a percentage of the control for each trial in which it occurs. Averaging these control percentages for each variety gives the mean percentages quoted in Tables 18 and 19. Neither the criterion of mean yield nor mean percentage of control is entirely satisfactory because of the inequality in the number of trials per variety and the evidence of marked site differences and of interaction between sites and varieties. This interaction appears more pronounced for yield than girth. Consequently, in the present study of the yield data, more attention has been directed to the mean yields than to the mean percentages, although the latter are shown for all the material except the old clones whose trials did not invariably contain the Pil B84 control.

The variability between estates has been estimated for each clone or seedling tested on more than one site. From these variances the inter-estate standard errors of the mean yields shown in Tables 17 to 19 have been calculated. The magnitudes of many of these inter-estate errors demonstrate the wide variability of a clone's performance on different sites. Intra-estate errors are also quoted for each clone and seedling, and represent averages of the errors encountered in testing a variety in its particular trials; they are not indicative of the variability between trials in which all varieties compared were not grown.

The relative progress of each variety in a given group during the first five years of tapping has been shown in these Tables by ranking the mean yields each year.

The difficulties of generalising from this amalgamation of trial records are evident. However, the objective is not to place each clone or seedling in precise relationship since this could not be expected to be equally applicable to all conditions in Malaya, but merely to indicate certain material as having generally superior yields and to make certain broad comparisons between clones and seedlings and between inland and coastal soils.

Comparison of Yields on Inland and Coastal Soils

In general, yields are higher on inland than on coastal soil. This is demonstrated by Table 20 below showing the mean yields of all the available clones and seedlings planted on both types of soils. The clones, which total 21, are:

RRIM 500 to 515, 518 to 520, 522 and Pil B84.

The clonal seedlings, which total 20, are:

PBISG 'CDE', Tjir 1, Tjir 16, Gl 1, Rub 393, Sab 24, BD 5, PB 86, SR 9, Bukit Rajah, Batu Kawan, Gadek, Buloh Akar, Pilmoor, RRIES Fds 2, 4A, 14AB, 16N, 18 and 22.

Yields are averaged over five years, and old clones are omitted because of incomplete data for the first year of tapping on the inland estates.

TABLE 20. MEAN YIELD (LB PER ACRE PER ANNUM). AVERAGE OF 5 YEARS

Planting material	(a) inland estates	(b) coastal estates	(b) as % of (a)
Clones	1263	1089	86
Seedlings	1011	852	84

On average, clones and seedlings both yield about fifteen per cent less on coastal than on inland soil.

It is well known that there is greater diversity between members of a seedling family than between trees of a given clone, and it has therefore been suggested that seedling families will be more adaptable than clones and that their yields will be less affected by soil type. But in the present data the yields of clones and seedlings are affected in very similar proportions and there is no support for this theory of clonal seedling adaptability.

Of varieties tested on both soil types, those listed below reveal marked differences between their inland and coastal ranks within their particular group. The following rank higher for yield on inland than on coastal soil:

Old clones:	Tjir 16, Rub 393
RRIM clones:	511, 520, 522, 503
Clonal seedlings:	Pilmoor, Bukit Rajah, RRIES Fd 16N, 14AB, 4A

The following rank higher for yield on coastal than on inland soil:

Old clones:	Lun N, Gl 1
RRIM clones:	504, 500, 519, 507, 515, 510
Clonal seedlings:	RRIES Fd 22, Sab 24 selfed, PB 86 illegitimate, SR 9 illegitimate

Yield and girth. In Table 21 the above list is combined with the similar list of varie-

TABLE 21. COMPARISON OF YIELD AND GIRTH RANKS ON INLAND AND COASTAL SOILS

YIELD RANK		GIRTH RANK: *Ranking higher on inland soil*	*Similar ranking on both soils*	*Ranking higher on coastal soils*
Ranking higher on inland soil	*Old clones*	Tjir 16 Rub 393		
	RRIM clones		511, 522, 520, 503	
	Clonal seedlings	RRIES Fd 16N	Bukit Rajah RRIES Fd 4A	Pilmoor RRIES Fd 14AB
Similar ranking on both soils	*Old clones*		PB 86, Tjir 1, Pil B84, Pil D65, BD 5	
	RRIM clones		501, 513, 509, 518, 508, 502, 506, 512, 514, 505	
	Clonal seedlings	Buloh Akar Gadek	RRIES Fds 2, 18, Rub 393 selfed, B. Kawan, PBISG 'CDE', Tjir 1 selfed, Tjir 16 selfed, Gl 1 selfed	BD 5 selfed
Ranking higher on coastal soil	*Old clones*			Lun N, Gl 1
	RRIM clones		504, 500, 519, 507, 515, 510	
	Clonal seedlings		RRIES Fd 22, PB 86 illeg., SR 9 illeg.	Sab 24 selfed

ties whose growth (girth) ranked differently on the two soil types. From a total of 49 varieties listed in the Table only 11 are considered to show exceptional differences between their girth ranks on inland and coastal soil, compared with 23 showing marked differences in yield ranks. This is due to the high degree of correlation between girths on inland and coastal soils among the RRIM clones.

Of the 11 varieties showing marked differences in girth ranks, the following 6 show similar differences in yield ranks: Tjir 16, Rub 393, RRIES Fd 16N, Lun N, Gl 1 and Sab 24 selfed.

A further three varieties show no marked difference in yield ranks between inland and coastal soil: Buloh Akar, Gadek, BD 5 selfed.

The remaining two varieties, Pilmoor and RRIES Fd 14AB, are exceptional in that for girth they rank much higher on coastal than on inland soil and yet the converse holds in terms of yield rankings.

Hence, although there is some indication that marked differences in girth rank between soil types is accompanied by similar differences in yield ranks, this association does not invariably apply.

Within their particular group the following varieties have relatively good yields on both inland and coastal soil:

Old clones:	PB 86
RRIM clones:	501, 513, 509
Clonal seedlings:	PBISG 'CDE', Tjir 1 selfed, RRIES Fd 18, Batu Kawan

and the following have inferior yields on both soil types relative to the other members of their group:

Old clones:	BD 5, Pil D65
RRIM clones:	505, 518
Clonal seedlings:	BD 5 selfed

Comparison of Group Mean Yields

Table 22 gives a summary by groups of the yields of the varieties listed in Tables 17 - 19. Each group contains material of widely differing quality, and the superiority of the average of one group over another may not necessarily apply to the best material in the groups compared. This aspect is discussed later. Group comparisons, like individual variety comparisons, may be biased by estate differences.

On inland soil the mean yield per acre per annum of the 40 RRIM clones (1128 lb) is significantly greater than the mean yield of the 29 clonal seedling families (1028 lb) which in turn is significantly greater than that of the old clones group (834 lb). This last group is averaged over four years only. Yields of the RRIM group increase markedly after the third year of tapping (Table 22), and the old clones show a marked yield increase in the final year. The clonal seedling group, however, shows little annual variation.

The three groups bear a different relationship to one another on coastal soil, but it should also be noted that the membership of the groups is not the same on the two soil types. In the trials on coastal soil the mean yield per acre per annum of the group of 20 RRIM clones (1101 lb) is nearly significantly greater than that of the group of 11 old clones (991 lb), which in turn is significantly greater than the mean yield of the group of 21 clonal seedlings (857 lb). On coastal soil the marked annual increases of the RRIM group are not sustained as they are in the inland trials, but the superiority of the RRIM group over clonal seedlings is evident from the beginning on the coastal estates.

The variability in yield between the clonal seedling families as measured by the group standard deviation, is less than the variability between clones of the RRIM group or between the old clones. This greater degree of uniformity between seedling families is observed each year and on both soil types.

Comparison of Selected Material from Each Group

So far the group comparison has been made using all the available material, but a similar pattern is obtained if we examine only a selection of the better material in each group.

TABLE 22. ANNUAL MEAN YIELDS OF RRIM 500 SERIES, CLONAL SEEDLINGS AND OLD CLONES GROUPS, LB PER ACRE PER ANNUM

Planting material	(a) Inland estate trials						(b) Coastal estate trials					
	Annual mean					5-year mean	Annual mean					5-year mean
	1	2	3	4	5		1	2	3	4	5	
RRIM 500 series	949	1056	1067	1204	1400	1128	1167	1045	961	1090	1256	1101
Clonal seedlings	1016	1035	1037	1097	966	1028	784	844	795	940	925	857
Old clones	—	746	817	820	987	834	966	873	958	970	1190	991
Standard error of mean yields (lb/acre/annum)												
RRIM 500 series	56	52	39	43	41	± 39	44	39	35	45	47	± 31
Clonal seedlings	27	23	21	31	24	± 20	17	15	17	21	25	± 17
Old clones	—	66	44	60	59	± 51	80	59	43	47	67	± 50
Number of clones or clonal seedlings per group												
RRIM 500 series	40	40	40	40	40	40	20	20	20	20	20	20
Clonal seedlings	29	29	29	29	29	29	21	21	21	21	21	21
Old clones	—	9	9	9	9	9	11	11	11	11	11	11
Range of group (lb/acre/annum)												
RRIM 500 series	1221	1168	984	1055	1282	902	820	608	556	695	915	633
Clonal seedlings	613	556	454	623	566	404	318	254	356	365	416	275
Old clones	—	698	427	545	558	501	989	675	482	560	814	546
Standard deviation of group (lb/acre/annum)												
RRIM 500 series	356	326	248	272	260	244	197	176	158	202	211	140
Clonal seedlings	144	124	115	166	127	106	80	70	79	97	114	77
Old clones	—	199	133	180	178	152	266	195	142	156	222	164

Note : First year yields are not available for all clones in the 'old clones' group on inland estate trials.

TABLE 23. CONSOLIDATED LIST OF THE BEST MATERIAL SELECTED FROM EACH GROUP

Inland estates						Coastal estates					
Material	Mean yield over 5 yrs (lb/acre/ann.)	Yield rank (out of 21)	Number of trials	s.e. of mean yield (lb/acre/annum) From inter-estate variances	From intra-estate variances	Material	Mean yield over 5 yrs (lb/acre/ann.)	Yield rank (out of 21)	Number of trials	s.e. of mean yield (lb/acre/annum) From inter-estate variances	From intra-estate variances
RRIM clones						*RRIM clones*					
RRIM 501	1485	1	11	± 103	± 17	RRIM 501	1421	1	4	± 130	± 17
511	1481	2	3	263	31	513	1345	2	3	189	22
513	1471	3	5	178	32	500	1201	4	4	114	17
520	1441	4	4	78	36	508	1182	5	1	—	42
527	1418	5	2	121	32	502	1158	7	1	—	42
526	1366	6	1	—	44	519	1117	9	2	160	25
508	1339	7	3	232	36	507	1071	11	2	62	23
Unweighted mean	1429 s.e. ± 22					Unweighted mean	1214 s.e. ± 47				
Clonal seedlings						*Clonal seedlings*					
PBISG 'CDE'	1233	8	5	130	19	PBISG 'CDE'	988	14	2	62	25
Tjir 1	1203	9	6	87	16	RRIM 507	960	15	1	—	37
RRIES Fd 18	1132	10	6	64	16	Tjir 1	942	16	2	143	25
RRIES Fd 14AB	1114	11	6	75	16	Batu Kawan	929	17	2	32	25
Batu Kawan	1100	12	7	66	14	RRIES Fd 22	927	18	1	—	37
RRIES Fd 18N	1060	14	4	106	17	Sab 24	907	20	1	—	37
Pilmoor	1049	15	7	76	14	RRIES Fd 18	904	21	2	113	25
Unweighted mean	1127 s.e. ± 26					Unweighted mean	937 s.e. ± 11				
Old clones						*Old clones*					
Tjir 16	1099	13	2	41	22	Gl 1	1223	3	2	209	16
PB 86	977	16	2	71	24	PB 86	1162	6	2	188	16
Tjir 1	932	17	2	36	24	Lun N	1156	8	2	66	23
Rub 393	856	18	1	—	30	Sab 24	1092	10	2	174	26
Gl 1	825	19	2	9	23	Tjir 1	1044	12	2	70	26
Pil B84	754	20	2	61	24	Tjir 16	1001	13	2	253	26
Lun N	753	21	1	—	30	Pil B84	920	19	4	91	16
Unweighted mean	885 s.e. ± 48					Unweighted mean	1085 s.e. ± 40				

Seven of the better clones or clonal seedlings have been chosen from each of the three groups, and the 21 selected varieties are listed in Table 23. Separate selections have been made for inland and coastal soils.

The selections from each group have been made primarily on the basis of mean yield per acre during the first five years of tapping, but some varieties with relatively high average yields have been disregarded because of susceptibility to brown bast, poor bark renewal, marked lack of vigour or, especially, because of clear indication of declining yield. In choosing between varieties with similar mean yields and secondary characters, their ratings in terms of percentage of control have also been considered.

Inland estates. For inland estates the unweighted mean yields of each group of seven selected clones or clonal seedlings are as follows:

RRIM clones:	1429 lb per acre per annum (s.e. ± 22 lb)
Clonal seedlings:	1127 lb per acre per annum (s.e. ± 26 lb)
Old clones:	885 lb per acre per annum (s.e. ± 48 lb)

The mean yield of the selected RRIM group is significantly greater than its clonal seedling counterpart by some 300 lb per acre per annum. In turn, the clonal seedlings significantly outyield the selected old clones by about 240 lb.

The highest average yielder on inland soil is clone RRIM 501 with a mean yield over 11 trials of 1485 lb per acre per annum. The highest yielders in their respective groups are RRIM 501, PBISG 'CDE' among the clonal seedlings, and Tjir 16 among the old clones. However, the first 7 ranks out of the 21 selections are occupied by RRIM 500 series clones. Consider, now, comparisons based on intra-estate errors whereby significant differences can be regarded as established only for those specific trials in which all the varieties compared were grown. On inland soil RRIM 501 significantly out-yields all the selected clonal seedlings and old clones, but its significant superiority over the other selected RRIM clones is not established with confidence except over RRIM 526 and RRIM 508. Of the seven selected clonal seedlings on inland soil trials, PBISG 'CDE' and Tjir 1 show no significant yield difference, but their superiority over the other clonal seedlings is established. In these particular inland trials, clone Tjir 16 significantly outyields the remaining old clones during these first five years of tapping.

Coastal estates. On coastal soil the unweighted mean yields of the selected groups are:

RRIM clones:	1214 lb per acre per annum (s.e. ± 47 lb)
Clonal seedlings:	937 lb per acre per annum (s.e. ± 11 lb)
Old clones:	1085 lb per acre per annum (s.e. ± 40 lb)

Thus, the mean of the selected RRIM group is a significant 280 lb per acre per annum greater than that of the clonal seedling group, and the difference between the RRIM group and the old clones group is very nearly established (probability about 0.6). The selected clonal seedling mean is also significantly inferior to the mean of the selected old clones in these coastal trials.

The highest yielder among the 21 selected varieties on coastal soil is again RRIM 501, and the highest yielders in the three groups are RRIM 501, PBISG 'CDE', and clone Gl 1. Tests of significance based on intra-estate errors show that the mean yield per acre of RRIM 501, in its four coastal trials, is significantly greater than the mean yields of the other six selected RRIM 500 series clones in their respective trials, and is also significantly superior to the highest-yielding clonal seedling or old clone. Differences between the selected clonal seedlings are small and are not established as significant except between PBISG 'CDE' and RRIES Fd 18.

Clone Gl 1 yields significantly more than each of the remaining six selected old clones in the trials on coastal soil.

Variability of performance. Attention has been drawn to the wide variability in a clone's performance on different sites, and if we reconsider our earlier varietal comparisons on the basis of inter-estate errors in an attempt to extend the conclusions beyond these particular trials, we find that few of the previous significant differences can be maintained with full confidence. Thus, although varietal differences observed in these trials may have widespread application, it is also likely that exceptions will occur.

CONCLUSIONS

It is premature to draw final conclusions from this work, since the trials are still continuing and no variety can be considered proven till it has been tapped on renewed bark as well as on virgin bark. However, it is possible to comment on certain aspects which are clear at this stage of the work, that is when tapping is approaching the end of the first cycle.

1. In respect of girth, the opinion that seedlings show greater vigour of growth than clones is substantiated under the conditions of these trials, but in respect of bark renewal there is a suggestion of better renewal by clones than by seedlings.

2. High susceptibility to brown bast is inherent in all the seedling families tested without exception, and this may therefore be true of all seedling families at present known. The level of susceptibility in clones ranges from high to very low—almost to the point of immunity. Selection of clones for immunity against this disturbance is possible, whereas selection of seedling families appears impossible.

3. In yield the best * of the new clones raised from hand-pollinated seedlings show a superiority over all other varieties tested.

4. The recommendations that can be made from the results described in the foregoing pages are briefly these:

Of all the varieties tested, RRIM 501 alone has yielded so consistently well and has been proven to be so outstanding, that it must receive special recommendation for planting either inland or on the coast.

With regard to the estates on which these trials took place the following varieties appear to be indicated for use:

Inland. RRIM 501 is proven superior to RRIM 526. Varieties in intermediate positions are not proven different from RRIM 501. These are RRIM 511, 513, 520 and 527. In fact the difference in mean annual yield over five years has been only 14 lb per acre for RRIM 501, 511 and 513. The use of any of these three clones is plainly recommendable.

Coastal. The choice here is restricted. There is one variety only in the top rank. RRIM 501 is proven to be in a class by itself, significantly superior to all other varieties. This in a way is unfortunate in that one would have preferred a selection to lessen dependence on one variety alone, but the evidence is quite clear.

Regarding estates generally, that is whether they had trials or not, the following results are statistically substantiated:

Inland. RRIM 501 is shown to be superior to Tjir 1 selfed seedlings. All varieties between are therefore not proven different from RRIM 501. These are clones RRIM

* The best of the new clones is emphasised here and elsewhere because it must be realised that not all clones made from hand-pollinated seedlings need necessarily be good. Obviously it is the best only in each group that the breeder and planter is interested in.

511, 513, 520, 527, 526 and 508 and PBISG 'CDE' seedling family.

Coastal. RRIM 501 is proven superior to RRIM 507. All between are therefore not proven different from RRIM 501. These are RRIM 513, Gl 1, RRIM 500, 508, PB 86, RRIM 502, Lun N, RRIM 519 and Sab 24.

However in the case of estates generally, the statistical tests are not highly sensitive and one may suspect that with the wide range of mean yield per acre covered by the varieties not proven different from RRIM 501, undetected differences do actually exist. The recommendation of varieties for planting based on statistical tests should be tempered with physical observation and limited perhaps to those in the upper part of the groups named above, that is: on inland soils, RRIM 501, 511, 513 and 520; on coastal soils, RRIM 501, 513, Gl 1, RRIM 500, 508 and PB 86. It will be noticed that in the foregoing recommendations the members of the old clones group, except Gl 1 and PB 86, and of the clonal seedlings group, fail to receive recommendation. Gl 1 takes a high place and PB 86 is a marginal inclusion on coastal soils.

The exclusion of the balance of the old clones and of all the seedling families is in accordance with the evidence obtained and there appears to be no justification for using such varieties in the face of proven superior clones, unless it be in exceptional circumstances or for a special purpose, as for example to obtain latex of certain technical qualities.

It may be argued by advocates of clonal seedlings that seedlings attain maturity much quicker than clones and that they do not require stocks to be grown first for budding. These are considerable advantages, but the time won in reaching early maturity is speedily lost when new high yielding clones come into tapping. On inland soils in these trials the crop obtained from PBISG 'CDE' seedlings in 5 years' tapping could be obtained in $4\frac{1}{2}$ years' tapping of RRIM 501. On coastal soils the difference is more marked; the equivalent of 5 years' tapping of PBISG 'CDE' was obtained in under $3\frac{1}{2}$ years from RRIM 501.

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A Survey of Factors Involved in an Experimental Study of the Drying of Sheet Rubber

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Aspects of the drying of sheet rubber are studied which include: the methods of preparation of wet sheet rubber and its dimensional changes during drying; the effect of drying conditions on drying rate, blister formation and technological properties; and the effect of relative humidity on the equilibrium water content. The data presented form the basis for further detailed investigations into the effect of drying conditions on drying rate and quality.

INTRODUCTION

Although the drying of sheet rubber is one of the more important processes in the production of dry rubber from field latex, only limited attention has been given to the theoretical aspects of the mechanisms involved. One of the most significant early contributions was by PIDDLESDEN (1937) who found two distinct phases of drying—a rapid reduction in water content down to about 10%, followed by a very slow rate of drying. It was postulated that this second phase was controlled by a diffusion mechanism, since the drying time was found to be roughly proportional to the square of the sheet thickness (a confirmation of an observation by VAN HARPEN, 1930) and also that the shape of the drying curve was in approximate agreement with classical drying diffusion theory (NEWMAN 1931, SHERWOOD 1929, SHERWOOD 1931). Observations, however, showed fairly wide variations from the average relationship between thickness and drying time, and consistent departures from the theoretical drying rate curve; the latter were attributed to dimensional changes and to the characteristics of the drying apparatus. Further, the day-to-day variability of drying characteristics did not allow an accurate assessment of the temperature co-efficient of the drying rate.

STEVENS (1948) expressed the view that the porosity of coagulum is reduced by compression during machining, and that the drying rate of an unmachined coagulum might be greater than that of machined sheet in spite of the former's greater thickness and initial water content.

PHILPOTT AND WALKER (1955) found that the inclusion in sheet of protein precipitants or tanning agents accelerated drying; coupled with the fact that drying is retarded both by removal of protein and the addition of sodium sulphite to latex (DE VRIES 1920), this clearly indicated the important rôle of non-rubber constituents.

In none of these investigations was the effect of relative humidity studied, but PIDDLESDEN (1937) anticipated, on the basis of the diffusion theory, that there would be no effect. The view was held in other quarters that increasing the relative humidity would prevent the formation of an impermeable skin on the surface of the rubber and thus increase the rate of drying.

In reviewing the need for further work it was clear that more information was required on the effects of temperature and humidity, since a knowledge of these two variables is vital to an economic assessment of the drying process: it was also evident that accurate data could only be obtained by paying attention to the many other factors likely to affect the drying characteristics. The investigations presented below in six sections form a preliminary survey of the effects of drying

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conditions on rates of drying and on the properties of the product.

As variations in sheet dimensions affect the drying rate, an investigation was made (Section 1) into methods of preparing wet sheet rubber and into dimensional changes of the sheet during drying. Section 2 is a report on the effect of drying conditions (temperature, humidity and air speed) on the rate of drying. Relative humidity is considered again in Section 3, where its effect on equilibrium water content is considered; techniques for determining the water content of sheet rubber are examined in Section 4. The last two Sections (5 and 6) are studies of the influence of drying conditions on blister formation and on the technological properties of the sheet.

1. FACTORS AFFECTING DIMENSIONS OF SHEET RUBBER

Dimensional changes in a sheet have a considerable bearing on its drying behaviour. Shrinkage in length and breadth reduces the area available for the evaporation of water, and changes in thickness affect the distance through which water in the interior of the sheet must diffuse before it reaches the surface.

Because of the marked effect of thickness, sheets for drying investigations should be as uniform as possible in this respect, and means for accurate measurement should be available. The thickness of a dry sheet is determined by the method of preparing the coagula, the degree of machining, and by dimensional changes during drying. A knowledge of the shrinkage of a material during drying also gives some indication of the mechanisms involved in water transport within the material.

Method of Preparation of Sheets and Measurement of Thickness

Preparation of sheets. Coagulating pans rather than partition-plate tanks were chosen since the coagulum can be removed from pans with less distortion, and also because there is less likelihood that the thicknesses of various parts of the coagulum will be affected differentially either by creaming of the latex or by compression due to buoyancy forces.

A pair of smooth rolls was used for machining, and the adjusting screws controlling the gap between the rolls were calibrated by measuring the thickness of lead strips passed between the rolls at the same time as strips of coagulum. To characterise the intensity of machining to which a coagulum is subjected (at constant d.r.c. of coagulation), use has been made of a machining ratio (M.R.), calculated by dividing the gap between the rolls by the depth of latex in the coagulating pan. To avoid undue variations in latex depth when preparing thin coagula, the pans were constructed of heavy gauge aluminium which ensured a flat base not liable to distortion.

Observations on wet machined sheets showed the usual feature of ridges along the edges (an unavoidable effect when using a coagulum of rectangular section), and also showed that unless there is a plentiful supply of water to the rolls the width of coagulum near the leading edge is less than that near the trailing edge. Furthermore even with a good supply of water the part of the sheet near the leading edge was more variable in thickness than was the remainder.

Because of the effects of pH of coagulation on the behaviour of coagulum during machining (see Table 1) it was considered desirable to coagulate at constant pH with a view to

TABLE 1. SERUM CONTENT (% OF DRY RUBBER) AND THICKNESS OF DRY SHEET (MM) FOR 8 SHEETS MACHINED TO M.R. 0.032

Property	pH of coagulation 4.0	4.5
Serum content 5 min. after machining	30, 42, 48, 47 *Average 42*	59, 56, 53, 54 *Average 56*
Dry sheet thickness	2.03, 2.27, 2.17, 2.17 *Average 2.13*	1.99, 1.98, 1.93, 2.03 *Average 1.98*

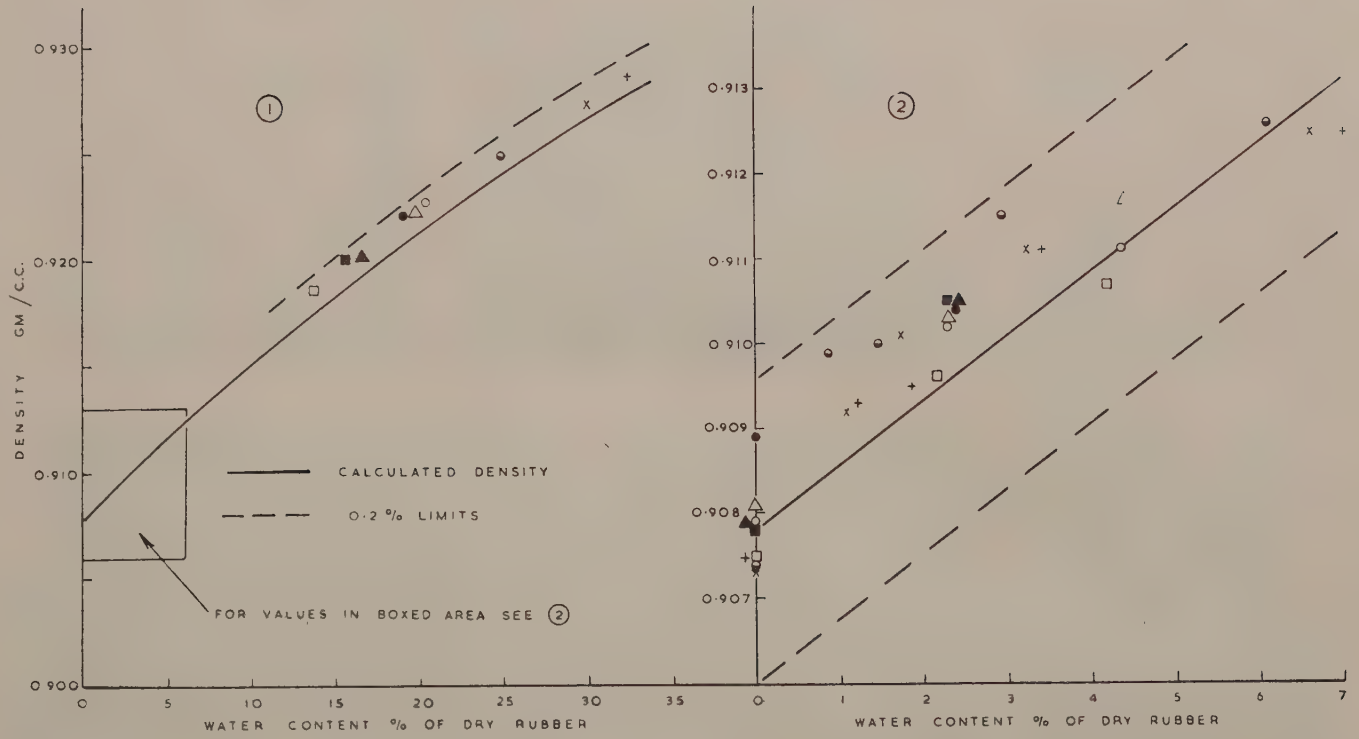

Figure 1. Density of nine samples of wet sheet rubber (c. 82°F), grams per c.c.

reducing day-to-day variation in the coagulum properties of a given latex.

Attention has been devoted almost entirely to coagula prepared from 15% d.r.c. latex and the emphasis has been on machining to a final M.R. of 0.032, since these conditions approximate to normal factory conditions.

Thickness measurement. The direct measurement of the thickness of freshly machined sheet is difficult owing to its softness and to the continued exudation of serum after it has left the rolls; in most cases therefore the thickness was calculated from the area of the sheet, its weight, and its density. The thickness of dry sheets was measured using a dial gauge mounted on a rigid arm above a cast-iron surface plate, the lower end of the gauge stem which is in contact with the rubber being 1 cm in diameter. The error introduced by the weight of the stem compressing the rubber was estimated by adding weights to the stem, taking thickness readings at each weight increment and extrapolating to zero weight the curve of thickness reading against total weight. The compression of dry sheets, ranging from 2 to 5 mm in thickness, caused by the weight of the stem alone was approximately 0.3%.

Dimensional Changes During Drying

A normal factory sheet, hung over a pole as in commercial rubber driers, shows a complex pattern of thickness variation. The most notable features, apart from the ridges formed by the edges of the coagulum, are the wide thin part in contact with the pole and the general tendency for increased thickness in the lower parts away from the pole.

Three mechanisms were thought to be responsible for this pattern—relaxation of machining stresses, shrinkage due to loss of water, and deformation caused by plastic flow of the sheet under its own weight—and each has been studied briefly.

Machining stresses. Rapid relaxation of the machining stresses in sample sheets machined to M.R. 0.032 was obtained with negligible water loss or effect of weight stress, by supporting the sheets horizontally on flat plates and exposing them to steam at atmospheric pressure. The shrinkage was 9% in length and 6% in width, causing an increase in thickness of about 17%.

Water loss. The shrinkage due to water loss was determined by measuring the density of sheets at various points in the drying cycle, using an immersion method similar to that described in B.S. 903; Part 14: 1950 (Procedure A), and the results for 9 samples are shown in Figure 1. The range of densities of the dry rubber (at equilibrium with laboratory atmosphere) is 0.9073 to 0.9089. WOOD (1938) quotes values from many sources at 77°F, the great majority of which lie in the range 0.905 to 0.919. Using Wood's selected value for the temperature co-efficient of volume expansion, this range becomes 0.903 to 0.917 at 82°F, the average temperature of our experiments, and the present results lie well within this range.

The solid lines in the Figure show the curve calculated on the assumption that the volumes of water and rubber are additive. The densities used for this calculation are 0.9960 for water (since only pure water is lost by evaporation) and 0.9078 (the average of the measured dry rubber values). All results are within 0.2% of the calculated curve. For all points above 1% water a much closer approach to the calculated curve would be obtained if this were calculated with a dry density 0.1% higher, but no conclusive explanation is offered for this.

The data show that as drying proceeds substantial voids are not left in the sheet; the rubber moves in to fill the space previously occupied by water.

Combined effect of machining and weight stresses. Assuming that shrinkage due to loss of water is uniform in all three dimensions, the linear shrinkage can be calculated from the above data. If the linear dimensions of a dry sheet are different from those calculated from the wet dimensions then deviations can be attributed to either machining or weight stresses.

Table 2 shows the actual dimensions as a fraction of those calculated assuming uniform

shrinkage for 8 sheets coagulated at 1 in. latex depth and pH 4.0 and pH 4.5, machined to M.R. 0.032, and dried at room temperature and at 120°F. The sheets were hung from one edge on a series of long hooks which were free to pivot, thus minimising restriction of width shrinkage. The wet dimensions were measured 5 minutes after the sheets left the rolls.

TABLE 2. ACTUAL DIMENSIONS OF DRY SHEET AS FRACTION OF CALCULATED DIMENSIONS. DEPTH OF LATEX 1 INCH

L = Length W = Width T = Thickness

Drying temp.	pH 4.0			pH 4.5		
	L	W	T	L	W	T
80–90°F	0.96	0.99	1.05	0.97	1.02	1.04
	0.98	0.99	1.03	0.98	1.00	1.03
120°F	0.96	0.99	1.08	0.96	1.00	1.07
	0.97	1.00	1.06	0.97	0.99	1.06

Although the accuracy of the experimental method is clearly not high, since the product of the length, width, and thickness values should be unity, the general effects can be seen. Owing to relaxation of machining stresses, both length and width are smaller than calculated and consequently the thickness is greater. At the higher temperature elastic stresses are more fully relieved, so giving a thicker sheet. No difference between pH's is established.

Table 3 shows further data for a range of thicknesses of coagulum all machined to M.R. 0.032 and dried at 120°F. The same effects are seen at all latex depths.

TABLE 3. ACTUAL DIMENSIONS OF DRY SHEET AS FRACTION OF CALCULATED DIMENSIONS. VARYING DEPTH OF LATEX

Latex depth, in.	L	W	T
½	0.94	0.98	1.09
¾	0.95	0.99	1.08
1	0.94	0.99	1.09
1¼	0.95	0.98	1.10
1½	0.94	0.99	1.09

The effect of a wider range of machining ratios is shown in Table 4.

TABLE 4. ACTUAL DIMENSIONS OF DRY SHEET AS FRACTION OF CALCULATED DIMENSIONS. VARYING M.R.

Final M.R.	L	W	T	Water content, % of dry rubber
0.14	1.10	0.94	0.95	151
0.094	1.06	0.97	0.99	107
0.067	1.04	0.98	0.96	81
0.047	1.01	1.00	0.98	57
0.032	0.98	1.01	0.99	41

There are definite trends in the width and length data which indicate that the weight stresses more than overcome the machining stresses at high machining ratios; in particular the actual length is greater than the calculated length.

Combined effect of water loss, machining stresses and weight stresses on small sample sheet. It was evident from the above that to produce a dry sheet of uniform thickness for experimental work it is necessary:

(i) to cut a sample sheet from the full sized wet sheet, avoiding areas known to vary in thickness
(ii) to minimise the effect of weight stresses by choosing a suitable length of sample and
(iii) to avoid a method of support which restricts width shrinkage.

Tests were therefore made to ascertain whether a sample sheet of 6 × 10 in. wet dimensions supported on four pivoting hooks 1½ in. long, would, under the effect of the various stresses, give a dry sheet of uniform dimensions.

Ten sample sheets were prepared by the standard method, machined to M.R. 0.032 and dried at 140°F; the thickness of each sheet was measured at 12 equispaced positions. The results showed no effect of weight stress, or of width restriction causing thinning near the top of the sheet, nor did further

storage of the sheets at 140°F for one week cause any reduction of thickness.

Sheets of these dimensions, supported in the way described, were finally selected for all experimental work on drying rates, the precise choice representing a compromise between many opposing factors. Average thickness nevertheless varied from 1.59 to 1.76 mm (± 5% of mean average) and statistical analysis showed significant differences (0.1% level) between the average thickness of individual sheets.

Intentional Restriction of Length and Width Shrinkage

Calculations showed that if contraction of width and length could be restricted the thickness would be reduced by about 20% compared with a sheet which is not restricted. A practical trial in which sheets were held in frames during drying confirmed this, and the drying rates of these sheets were correspondingly greater than those supported on hooks.

Summary and Conclusions

If weight stresses are negligible and shrinkage is not restricted, the surface area of a sheet (machined to M.R. 0.032 and containing say 40% water) is reduced by 14.5% owing to the relaxation of machining stresses and by a further 16% owing to water removal during drying. Relaxation of machining stress increases the thickness, and water removal reduces it; the overall effect is to produce a dry sheet 5% thicker than the original wet sheet.

The size of the sheet affects the weight stress, and the method by which it is supported affects the degree of shrinkage restriction. To obtain a sheet of uniform thickness for experimental work it is necessary to keep weight stresses low and not to restrict the width shrinkage at the top of the sheet which occurs if a pole is used as a support. This can be achieved by having a sample sheet 6 × 10 in. and supporting it on hooks which are free to pivot. Even using standardised coagulation, machining, sample cutting, and supporting methods there are still significant differences in dry thickness between individual sheets, and this emphasises the need for measuring the thickness of each sheet in a batch of nominally similar sheets.

The intentional restriction of shrinkage gives sheets of reduced thickness which, as a consequence, dry more rapidly. It is possible that, after further study, some means of using this effect to accelerate drying on a commercial scale could be found.

The measurement of shrinkage due to water removal has enabled the effect of machining and weight stresses to be assessed. The results have also suggested that since no voids are left in the rubber during water removal, capillarity is not much concerned in the mechanism of water transport within a sheet.

2. EFFECT OF DRYING CONDITIONS ON DRYING RATE

Before designing an experiment for a detailed examination of the effect of drying conditions, it is necessary to know the likely magnitude of the effect of extreme changes in the main variables (i.e., temperature, humidity and air speed) on the various stages of drying.

The classical theory of the drying of solids by evaporation recognises three phases of drying:

(i) A 'constant rate' period when the surface is completely wetted with water
(ii) A period of unsaturated surface drying when only part of the surface is wetted
(iii) A period during which the surface is almost dry and water diffuses slowly from the wet interior to the surface

The transitions between the first and second, and second and third phases, are termed the first and second critical points respectively.

PIDDLESDEN (1937) observed that the initial part of the drying curve for rubber was approximately linear, and that the drying rate was rapidly reduced below 10% water content. He concluded that the surface of the sheet was saturated with water in the initial stages and that the second critical point occurred at about 10% water. In observations of the behaviour of sheet in commercial

driers, however, it was noticed that dripping which had almost ceased at room temperature, was renewed when the sheet was placed in the drier. The possibility of condensation from the air in the drier could not be ruled out entirely, but it seemed more likely that spontaneous exudation or syneresis, similar to that found by SCHOON (1953) for unmachined coagula, was responsible and that it provided another mechanism by which a sheet could lose water in the initial stages.

The experiments recorded below fall into three categories: evaporation in the phase down to about 10%, syneresis, and drying below 10%.

Evaporation in the Initial Period of Drying

Earlier workers considered that the approximate linearity of the water content/time plot indicated that the effects of temperature and humidity on the drying of sheet would be similar to those on evaporation from free water surfaces. To establish this more fully the initial phase has been studied in more detail.

Experimental procedures. Studying this period presents some difficulties because of the very rapid rate of drying. Weighing the sheet in the air stream introduces weighing errors and frequent removal during drying interrupts the drying unduly. Another method which can be used to study changes in drying rate is to measure the temperature difference between the sheet and the drying air; at constant air speed and in the absence of radiation effects, the rate of heat transfer, and thus the rate of evaporation, is proportional to this temperature difference. The method has the disadvantage that absolute drying rates are not measured and accuracy becomes poor at low rates of evaporation. It is however a useful method of investigating the shape of the drying curve at high rates of evaporation, and has been used in these investigations.

A thermocouple made of 40-gauge wires was inserted into the latex in a coagulating pan just after acidification. The coagulum was then carefully machined with the wires in position. This gave a wet machined sheet with the thermocouple firmly embedded in the centre of the sheet, the wires emerging from the edge of the sheet. A further thermocouple to measure the air temperature was then attached. The current flowing in the opposed couple circuit was measured with a galvanometer, which gave a direct reading of temperature difference between the sheet and the air.

Discussion of results. Figure 2 shows the measured temperature difference for sheets dried at 140°F/61% R.H. and 137°F/16% R.H. The almost constant initial values equal to the difference between the wet and dry bulb temperatures of the air confirms that during this period the surface is saturated with serum of a vapour pressure almost equal to that of pure water (i.e. the sheet is behaving like a wet bulb thermometer). The sharp downward turn at the end of the constant temperature difference period is clearly the first critical point. The next section of the curve represents falling temperature difference: it is likely that the end of the straight portion of this section corresponds with the second critical point; this occurs when the temperature difference is about half the initial value. In a further experiment drying was stopped at this level of temperature difference and the water content was found to be 9%.

Data from experiments in which temperature measurements were not made but in which weight loss was measured suggested that the first critical point occurs at about 15% water content.

Syneresis

During the high humidity experiment described above (Figure 2) serum dripped from the lower edge of the sheet during the first part of the constant temperature difference period, and the mechanism of this effect was considered to be worth investigating in more detail. To eliminate evaporation effects the loss of weight of freshly machined sheets was studied at 100% R.H.

Experimental procedures. 7 × 3 in. samples were cut from sheets and hung in pairs in sealed 2-litre bottles each containing 500

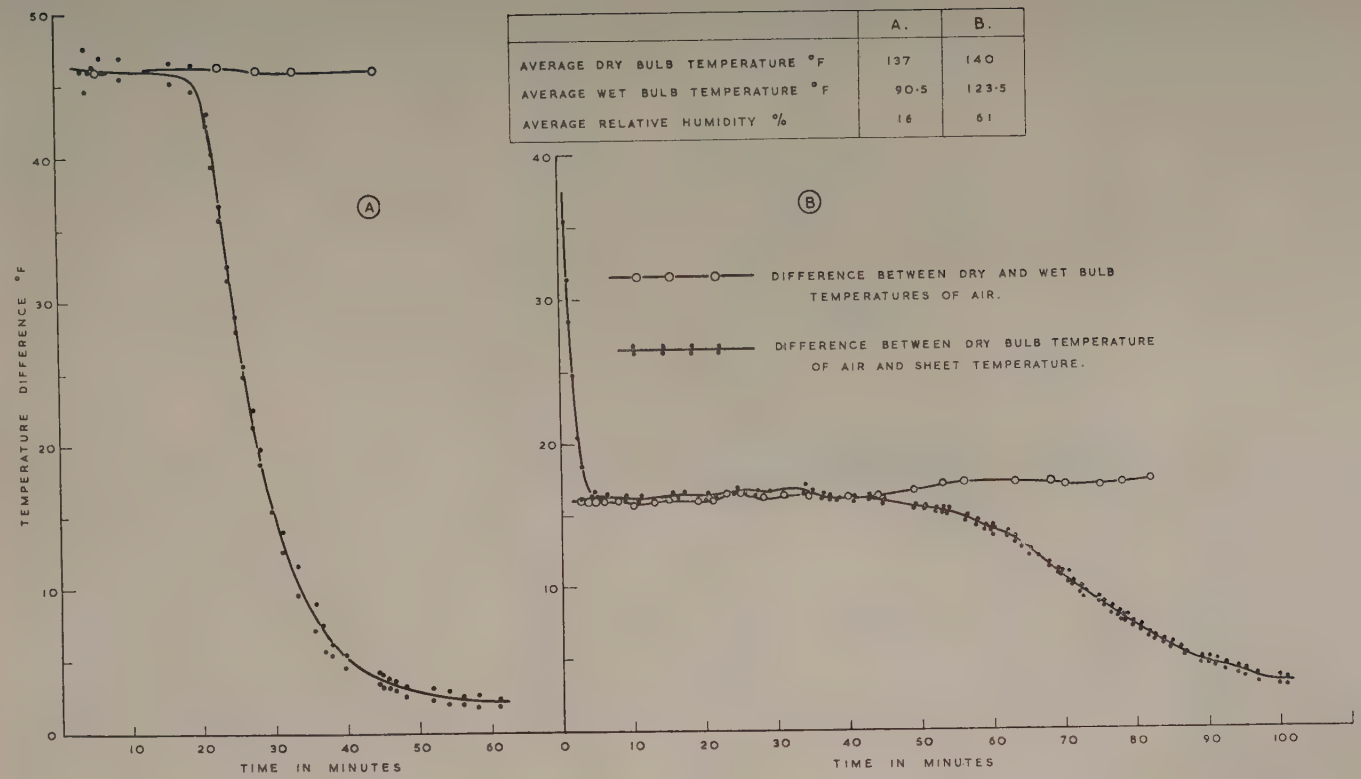

Figure 2. Temperature difference between sheet and air during initial stages of drying at 137°F/16% R.H. and 140°F/61% R.H.

c.c. of water. After about two hours some bottles were placed in an oven at an elevated temperature while others remained at room temperature. The bottles in the oven were lightly sealed during the heating period and were finally tightened when top temperature had been reached. The samples were removed periodically for weighing. Preliminary tests showed that removal for weighing did not seriously affect the measured weight loss.

Results. The following Tables (5 and 6) show the loss of serum for sheets machined to two levels of M.R., at two levels of pH. The results are plotted in Figure 3.

TABLE 5. SERUM CONTENT (PERCENTAGE OF DRY RUBBER) OF PAIRS OF SHEETS AFTER VARYING PERIODS OF STORAGE AT 100% R.H. M.R.0.094

Time hrs	Temperature	pH			
		4.0		4.5	
0	Room temp. c.85°F	113.0	121.0	140.0	153.0
2		95.6	104.0	120.0	134.0
4½		90.5	99.5	111.0	125.0
23		78.9	83.0	98.3	108.0
28½		76.6	82.2	95.3	105.0
47		73.1	78.4	87.2	94.5
0	c.85°F	119.0	114.0	148.0	143.0
2		101.0	95.5	133.0	129.0
4½		86.1	83.8	111.0	108.0
23	140°F	60.2	59.2	78.7	78.2
28½		59.3	58.7	77.1	76.9
47		57.2	56.9	73.7	72.6

TABLE 6. SERUM CONTENT (PERCENTAGE OF DRY RUBBER) OF PAIRS OF SHEETS AFTER VARYING PERIODS OF STORAGE AT 100% R.H. M.R.0.032

Time hrs.	Temperature	pH			
		4.0		4.5	
0	Room temp. c.85°F	47.4	50.9	61.3	68.4
2		33.3	36.1	45.7	49.7
4½		30.1	33.2	42.1	46.2
23		25.7	28.5	37.4	41.3
28½		24.2	26.9	36.1	39.7
47		22.3	25.2	32.4	35.4
0	c.85°F	47.9	48.0	64.3	58.9
2		36.7	36.3	48.8	44.7
4½		27.5	27.1	37.7	34.4
23	140°F	16.2	20.0	29.0	25.4
28½		15.7	19.8	28.3	25.3
47		15.2	19.3	27.7	24.8

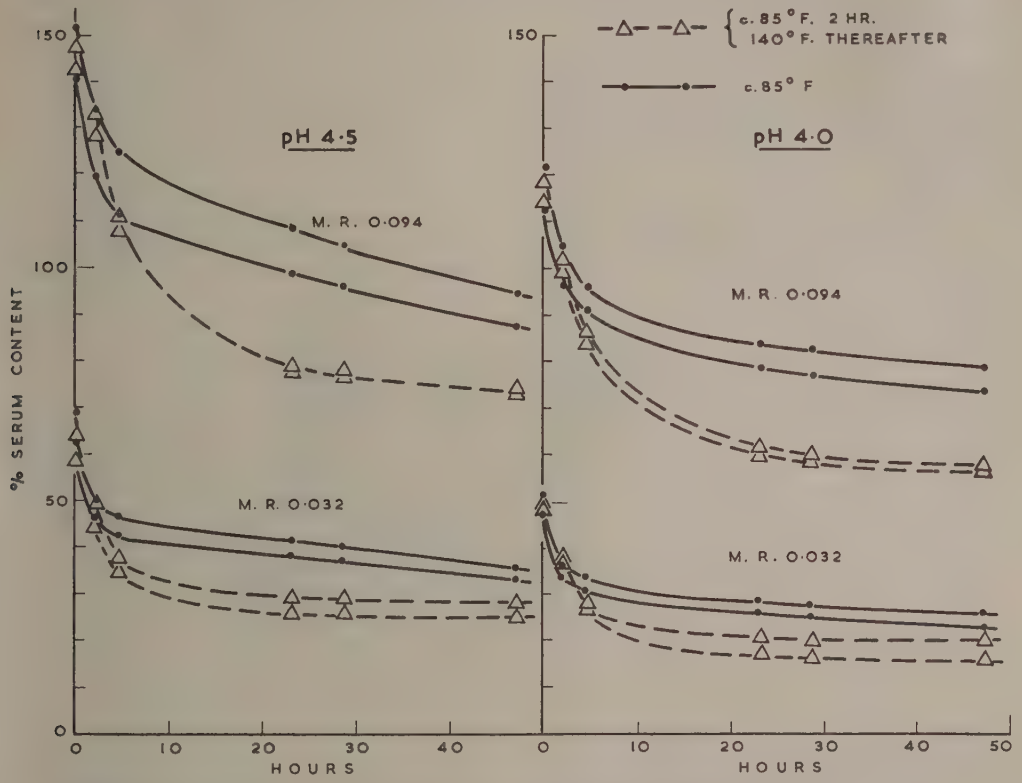

Figure 3. Exudation of serum from machined sheets. Serum content expressed as percentage of dry rubber.

Discussion of results. Sheets machined to M.R. 0.032 show losses of 11–19% during 2 hours at room temperature. During a further 2½ hours the extra loss at room temperature is 2.9–3.6%, and at 140°F 9.2–11.1%. This latter rate of loss is of the same order as the total initial rate of loss, by all mechanisms, obtained in commercial natural-convection driers operating at 140°F, and is therefore likely to contribute to the water loss in such driers.

The data also have some interesting features which give indications of the mechanism of syneresis. Sheets machined to M.R. 0.032 and held at 140°F almost reach equilibrium values, and those at room temperature could well be tending to the same average equilibrium value. Sheets with a high serum content do not reach equilibrium at either of the temperatures, but they are tending towards an equilibrium which is at a much higher level than for sheets with an initially low serum content. Each sheet however seems to have a separate equilibrium value which depends on its initial serum content. This applies for all sheets whether the variation in water content is due to differences in pH of coagulation, intensity of machining, or to random variations within the single sheet from which the sample sheets were cut. As also observed in the data in Table 1 the effect of increasing

the pH from 4.0 to 4.5 is to increase the serum content after machining.

A tentative explanation of this latter effect is that the coagulum prepared at pH 4.5 is softer and spreads out more easily during machining and is therefore subjected to less compressive stress than the firmer coagulum at pH 4.0.

It seems that the extent to which syneresis can occur depends to a large extent on the stresses set up during machining.

Drying Below 10% Water Content

Minor variations in serum composition or changes in the method of preparation are unlikely to affect the rates of drying in the constant rate period and it is probable that their effect would be noticed mainly in the diffusion-controlled period below 10% water content. In studying this phase in the drying process some attention was therefore given to measures for controlling the variation in non-rubber content and composition so as to reduce the day-to-day variability in drying rates. Such variations are considerable between latices from different clones and localities. The type of tapping cut and the time from the opening of a new tapping panel also influence the composition of the latex. An area of the Rubber Research Institute Experiment Station at Sungei Buloh (Tasks 7 and 8 of Field 25, Section V) was therefore selected as a source of latex for the experiments. The area was regarded as suitable because it was planted in 1931 with trees grown from seeds selected from a large number of high yielding trees on estates, and would be expected to give a fairly 'average' latex; also no manuring, stimulation or opening of a new tapping panel was expected for several years after the start of our experiments.

The control of pH was considered essential because of the effect of pH on the retention of non-rubber in sheet (LIPONSKI AND D'AUZAC 1955).

Experimental procedures. A preliminary experiment indicated that there might be some relationship between drying time and the order of acidification of the latex in the series of coagulating pans. To eliminate any doubts on this score an apparatus was constructed to enable two operators to acidify 16 pans of latex with an interval of only 15 seconds between the first and last pans, and to stir them simultaneously.

Coagula were prepared from the standard latex at a latex depth of 1 in. and pH 4.0, and machined to M.R. 0.032. Sample sheets were hung in the manner described in Section 1 for a fixed period at room temperature, and dried in an apparatus which enabled sheets to be weighed in a still atmosphere of temperature and humidity similar to that of the drying zone. The ten positions in the drying zone each had a separate air speed, the range of values being from 75 to 400 feet/minute.

Results. Figure 4 shows the results of three drying experiments carried out on different days, in each of which 10 sheets were dried at one time. The drying conditions for the three experiments were:

190°F, 5% R.H. (normal atmospheric absolute humidity)

140°F, 15% R.H. (normal atmospheric absolute humidity)

140°F, 70% R.H.

The units of the abscissa (time, θ, divided by the square of the thickness, t) provide an approximate correction for variations in thickness between individual samples. The curves give the outer limits of all points obtained with one batch of 10 sheets. The following Table gives the range of thicknesses, and the values of θ/t^2 for drying from 10% to 0.5% water, together with the percentage deviation.

Discussion of results. From Table 7 it can be seen that raising the temperature from 140°F to 190°F at constant absolute humidity has reduced the drying time by a factor of 2.65. Some of this effect is no doubt due to the reduced relative humidity at the higher temperature, since reducing the relative humidity from 70% to 15% at 140°F has reduced the drying time by a factor of 2.7, but no complete separation of the effects can be obtained from the present data.

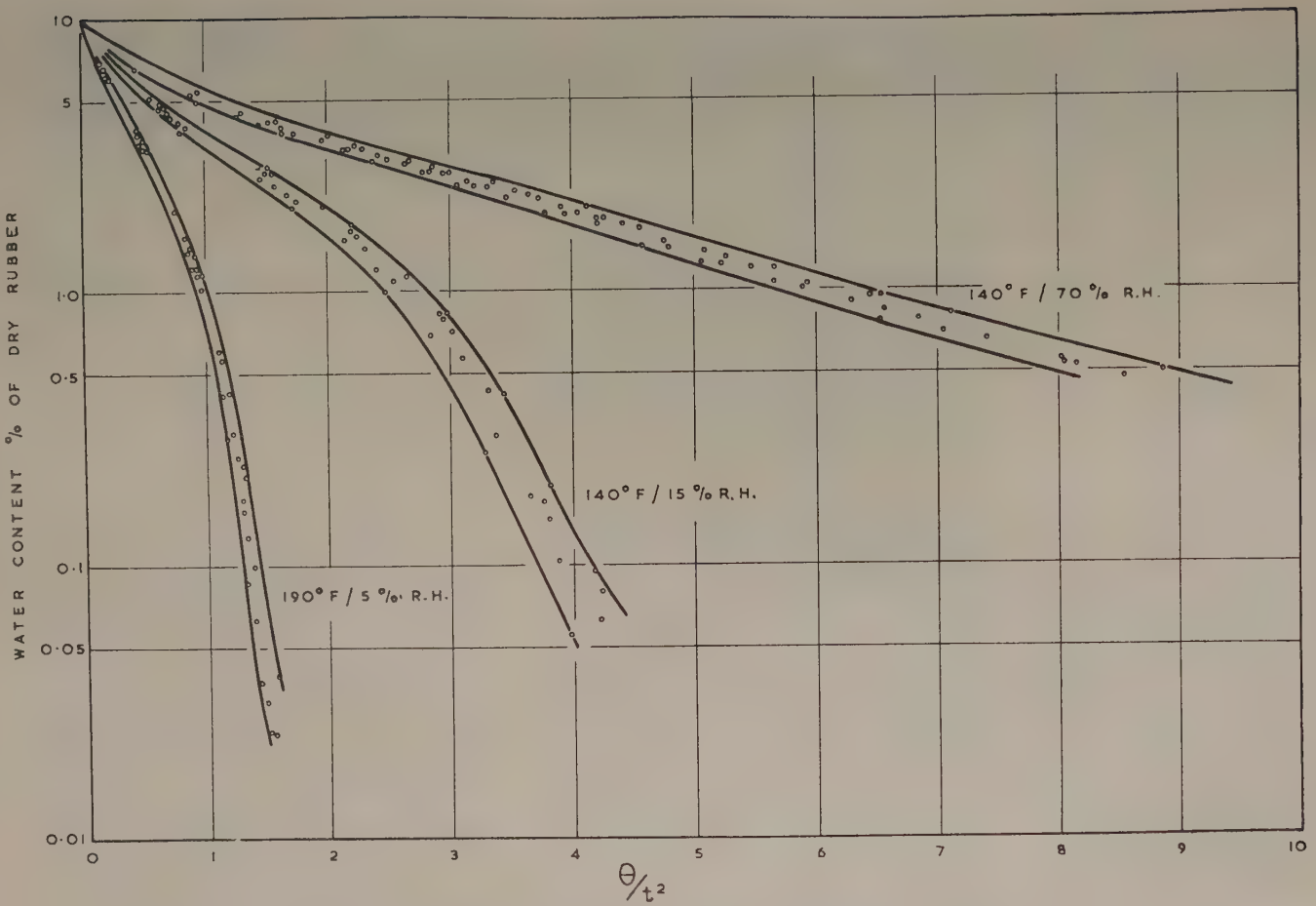

Figure 4. Drying below 10% water content; various drying conditions.
θ = time in hours. t = thickness in millimetres.

TABLE 7. DRYING BELOW 10% WATER UNDER VARIOUS DRYING CONDITIONS

θ = *time in hours.* t = *thickness in millimetres.*

Drying conditions	190° F/5% R.H.	140°F/15% R.H.	140°F/70% R.H.
Range of average sheet thickness, mm	1.98 to 2.15	1.59 to 1.76	1.75 to 1.88
Average θ/t^2 at 0.5% water, and % deviation	1.14 ± 4%	3.15 ± 6%	8.43 ± 5%

The very marked effect of relative humidity is of the greatest importance since it indicates that in commercial drying there will be an optimum humidity to give the most favourable economic balance between capital and fuel costs.

The range of variation in the corrected drying times between the 10 sheets in a single batch is only of the order of 10%. This variation is made up of experimental errors in the measurements of time, thickness, and water content, the possible inaccuracy in using the square of the thicknesses for correction of the time, and a variation in air speed ranging from 75 to 400 feet/minute. It can therefore be concluded that the effect of this range of air speeds is very small.

Conclusions

From temperature measurements of sheet during the initial stage of drying it can be predicted confidently that the evaporation rate during this stage will conform to the equations applicable to the evaporation from free water surfaces. The main features of such equations (PEARSE, OLIVER AND NEWITT 1949) are that the rate of evaporation per unit area will, in the absence of radiation or conduction effects, be determined by the difference between the wet and dry bulb temperature of the air, the air speed, and the dimensions of the sample.

The rate of loss of serum and/or water will however be affected by dripping from the sheet, which occurs when the rate of evaporation is less than the rate of syneresis. The balance between these two rates under different drying conditions has not been examined in detail but it is clear that raising the humidity at constant temperature and air speed will decrease the rate of evaporation and increase the rate of syneresis owing to the higher sheet temperature. It can therefore be expected that the variation in the rate of loss of water (particularly at low air speeds) will be less than if evaporation were the only mechanism of water loss, since at high humidities dripping will partially offset the reduced evaporation rate. Some insight into the mechanism of syneresis has also been obtained.

In the period below 10% water content when diffusion is the controlling factor, the effect of temperature (140°F to 190°F) is of the order to be expected from earlier work in a lower range of temperature, but the effect of humidity (15% to 70% R.H.) is unexpected and runs contrary to previously held views. The effect of air speed in the range 75 to 400 feet/minute appears to be small.

Calculations not presented in this paper indicate that from the point of view of thermal efficiency high temperatures are likely to be more economic, and that there would be an optimum humidity for the most economic operation.

It has thus been concluded that in future investigations the accent should be placed on temperatures higher than the normal 140°F and that the effect of humidity should be examined in more detail.

3. EFFECT OF RELATIVE HUMIDITY ON EQUILIBRIUM WATER CONTENT

Since it was considered that the effect of humidity on drying rate described in Section 2 was almost certainly associated with the change in equilibrium moisture content of the rubber, a brief examination of this property in freshly prepared air dried sheet was made.

Experimental procedures. Latex was diluted to 15% d.r.c. and coagulated at 1 in. latex depth and pH 4.5 with 1% formic acid, and machined to M.R. 0.032. From each of the sheets from seven coagulating pans four smaller sheets were cut. These twenty-eight sheets were assigned randomly to the various subsequent treatments. The sheets were dried at 140°F and then further dried to equilibrium over freshly dried silica gel at room temperature.

The dried sheets were then exposed to atmospheres of a range of constant relative humidities, obtained by using saturated solutions of various salts (WEXLER AND HASEGAWA 1954, WINK AND SEARS 1950). Half the sheets were maintained at 72°F, and the other half at 140°F. The samples were removed for weighing at intervals of several days. To correct for any absorption or desorption during weighing, readings were taken at short intervals and the required weight was obtained by extrapolating the readings to zero time.

In earlier preliminary experiments, mould had grown on the sheets at relative humidities above 80% and some additional sheets were soaked for 15 minutes in a 0.1% solution of *para*-nitrophenol after machining, and tested for comparison.

Results. The results are given in Table 8. The data show significant differences in water absorption due to humidity changes, but the picture is complicated by the occurrence of mould growth and the side effects of the *para*-nitrophenol treatment. The latter was effective in preventing mould growth at all

TABLE 8. EQUILIBRIUM WATER CONTENT. PERCENTAGE OF DRY RUBBER

Salt	Relative humidity % at 72°F	Relative humidity % at 140°F	Water content, % d.r. at 72°F	Water content, % d.r. at 140°F	Additional treatment
Potassium sulphate	97.0	—	2.61*	—	Nil
			2.72*	—	Nil
			2.04	—	P.N.P.
			2.00	—	P.N.P.
Potassium nitrate	93.0	—	1.31*	—	Nil
			1.49*	—	Nil
			1.06	—	P.N.P.
			1.08	—	P.N.P.
Ammonium sulphate	80.5	79.0	0.71	0.82	Nil
			0.69	0.87	Nil
			0.66	—	P.N.P.
			0.51	—	P.N.P.
Sodium chloride	75.5	74.0	0.58	0.77	Nil
			0.55	0.67	Nil
Magnesium nitrate	54.5	43.5	0.28	0.27	Nil
			0.25	0.28	Nil
Magnesium chloride	33.5	31.0	0.16	0.12	Nil
			0.16	0.15	Nil
Lithium chloride	12.0	11.5	0.06	0.02	Nil
			0.06	0.00	Nil

* Indicates presence of mould growth.

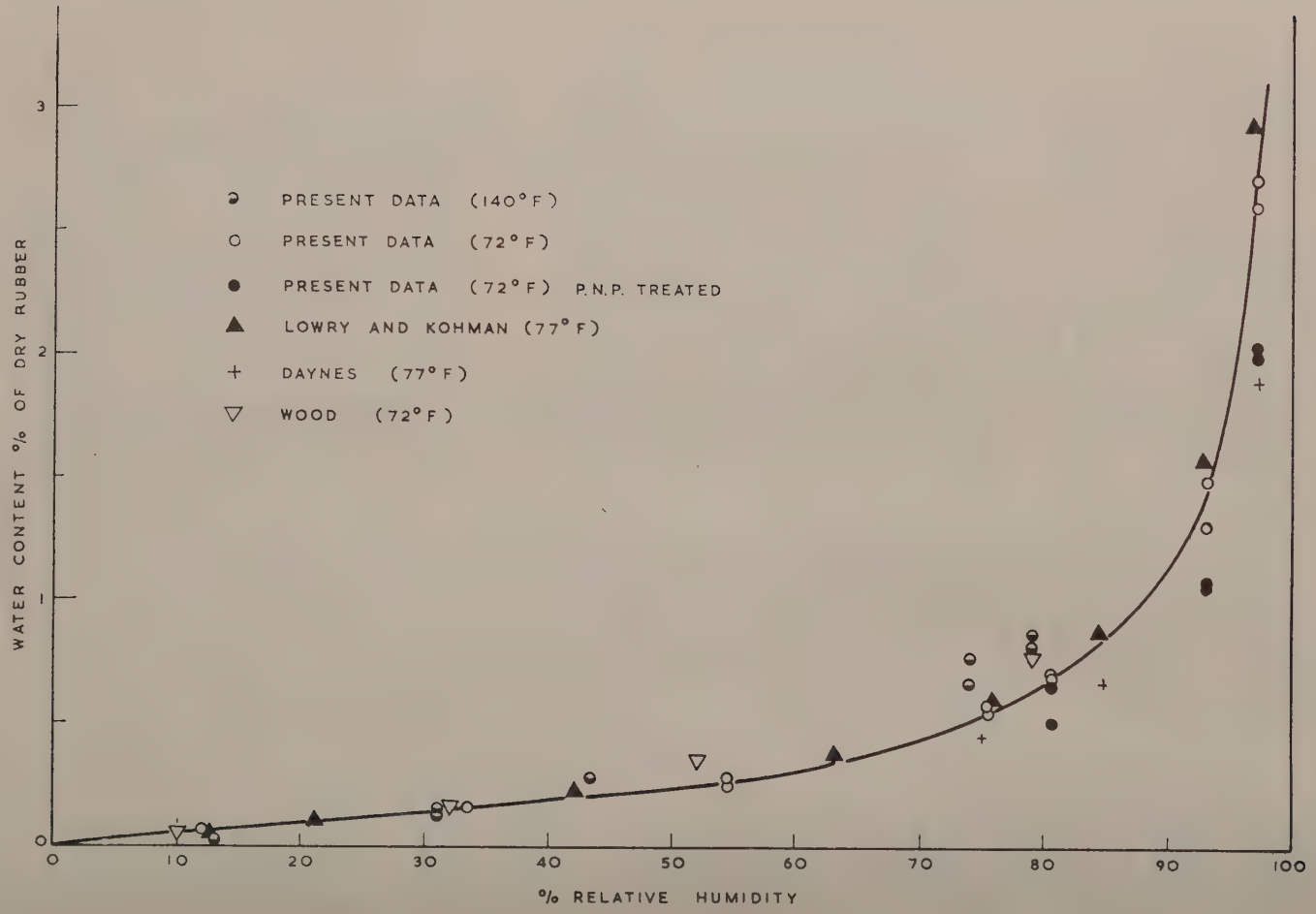

Figure 5. Equilibrium water content of sheet rubber.

humidities, but at 80.5% R.H. where neither treated nor untreated sheets supported mould growth, the water absorption was lower for the treated sheets. The data for treated sheets at 80.5% R.H. and above cannot therefore be regarded as an extension to higher humidities of the data for untreated sheets at 80.5% R.H. and below.

The results are plotted in Figure 5 and compared with data from other sources.

Our data show good agreement with those of LOWRY AND KOHMAN (1927) for smoked sheet, and the data of DAYNES (1932) and WOOD (1952) follow the same general trend. The points for Wood's data were calculated from the change in weight after 30 days.

No great accuracy is claimed for the high temperature results but they do at least show that the effect of raising the temperature is likely to be small.

Discussion and Conclusions

The data have shown that the equilibrium water absorptions of freshly prepared air dried sheet are similar to those of fairly fresh milled smoked sheet (WOOD 1952), and also to those of sheet used in investigations in consuming countries which is likely to have been stored for a period. It is therefore possible to draw some conclusions in relation to our work from the more extensive work of previous investigators in the consuming countries.

In particular LOWRY AND KOHMAN (1927) showed that intensive water washing of commercial smoked sheet reduced the water absorption at 98% R.H. almost in proportion to the weight of water extractables remaining in the rubber. On this basis the amount of washing received by wet rubber during and after machining should be carefully controlled if uniform hygroscopic properties are to be obtained.

In the experiments reported above all samples were translucent. The point at which a sheet becomes translucent is therefore not a satisfactory criterion for the end point of the drying operation from an experimental point of view, although it is the one used in commercial practice. A more satisfactory method is to determine the point at which the sheet reaches that water content which it would have when in equilibrium with a constant relative humidity. A relative humidity of 60% was chosen as approximating to the minimum atmospheric humidity in Malaya. In commercial operation any drying below this water content would not be of great use since the sheet, once removed from the drier, would re-absorb water from the atmosphere.

4. DETERMINATION OF THE WATER CONTENT OF SHEET RUBBER

The data in Sections 2 and 3 showed that the large decrease in drying rate caused by changing the humidity from 15% R.H. to 70% R.H. is associated with a change in equilibrium moisture content of about 0.4%.

Since in the main investigation it was planned to attempt to correlate drying rate with equilibrium moisture content, a convenient method was required for determining the dry weight of the samples on which to base the calculation of water content.

The direct method of moisture determination by azeotropic distillation was regarded as unsuitable, since only small samples can be conveniently handled and thus sampling from the sheets presents an added difficulty. Attention was therefore devoted to methods in which the whole sheet is weighed before and after equilibrating with an atmosphere having very low water-vapour pressure. These methods have the added advantage that they only determine the free moisture, i.e. the moisture which can be removed by air drying.

The problem resolves itself mainly into finding a convenient way of obtaining the low humidities required to reduce the equilibrium moisture content to a sufficiently low level.

Vacuum Drying and Drying with Desiccants

Experimental procedures. The vacuum apparatus consisted of a glass vacuum line using both mechanical and mercury diffusion pumps, to which the tubes containing the

TABLE 9. AVERAGE EQUILIBRIUM WATER CONTENT

Percentage of dry rubber at c. 85°F

In equilibrium with	d.r.c. of latex at coagulation	
	10%	25%
Vacuum 0.01 mm mercury	Assumed zero	Assumed zero
Silica gel containing 6.1% water	0.08	0.09
Silica gel containing 12.5% water	0.14	0.16
Laboratory atmosphere	0.36	0.44
R.H. c.80% (saturated ammonium chloride)	0.61	0.80

samples could be fitted. Pressure readings were taken with a MacLeod gauge. After pressure equilibrium had been reached the glass connecting-tubes were sealed off with a blow torch. The seals were broken immediately before placing on the balance pan for weighing, and readings were then taken at short time-intervals. The weight immediately after breaking the seal was obtained by plotting weight against time and extrapolating to zero time.

Desiccants were regenerated by heating to constant weight at 570°F for silica gel and 390°F for activated alumina. Whenever rubber samples or desiccants were weighed either tubes which could be rapidly sealed were used, or the weighings were corrected by using the plot of weight against time. Saturated salt solutions were used to give atmospheres of constant relative humidity. 75% sulphuric acid solution was used to obtain an atmosphere of 1.8% R.H. at 85°F, the relative humidity being calculated from vapour pressure data given by PERRY (1950).

Comparison of Vacuum Drying with Silica Gel and Alumina Drying

Vacuum drying yields the most reliable data but it is time-consuming and not easily adaptable to the handling of large numbers of samples. An experiment was, however, carried out to compare vacuum drying at a pressure of 0.01 mm mercury with drying over silica gel. Since it was suspected that the hygroscopic nature of the final sheet would vary with dilution of the latex, sheets were prepared by coagulation at 10% and at 25% dry rubber content, which represent the extreme limits for normal coagulation techniques. Both types of sheet had a nitrogen content of 0.34%.

The results in Table 9 show that the sheets coagulated at 25% d.r.c. are more hygroscopic than those coagulated at 10% d.r.c. Silica gel containing 6% of water reduces the water content of both types of sheet to less than 0.1%, assuming that vacuum drying gives the true dry weight. Silica gel and activated alumina were then compared for their effectiveness as desiccants. Table 10 shows the water absorptions of the desiccants at various relative humidities.

In Figure 6 the results are compared with those obtained by other workers. There are considerable differences between the data of CARTER (1951) and the present data, which are possibly due to the difference in temperature. The silica gel data also differ from those of RAO (1941) but SING and MADELEY (1954) have shown that large variations occur in the water absorbing capacity of silica gel, owing to differences in the conditions of preparation, particularly the pH. In these experiments, normal commercially available grades of desiccant were used.

The results show that the activated alumina is far superior to silica gel, and at 5% water (a convenient level for avoiding too frequent regeneration) will give a relative humidity of about 2.5%. The water content which a

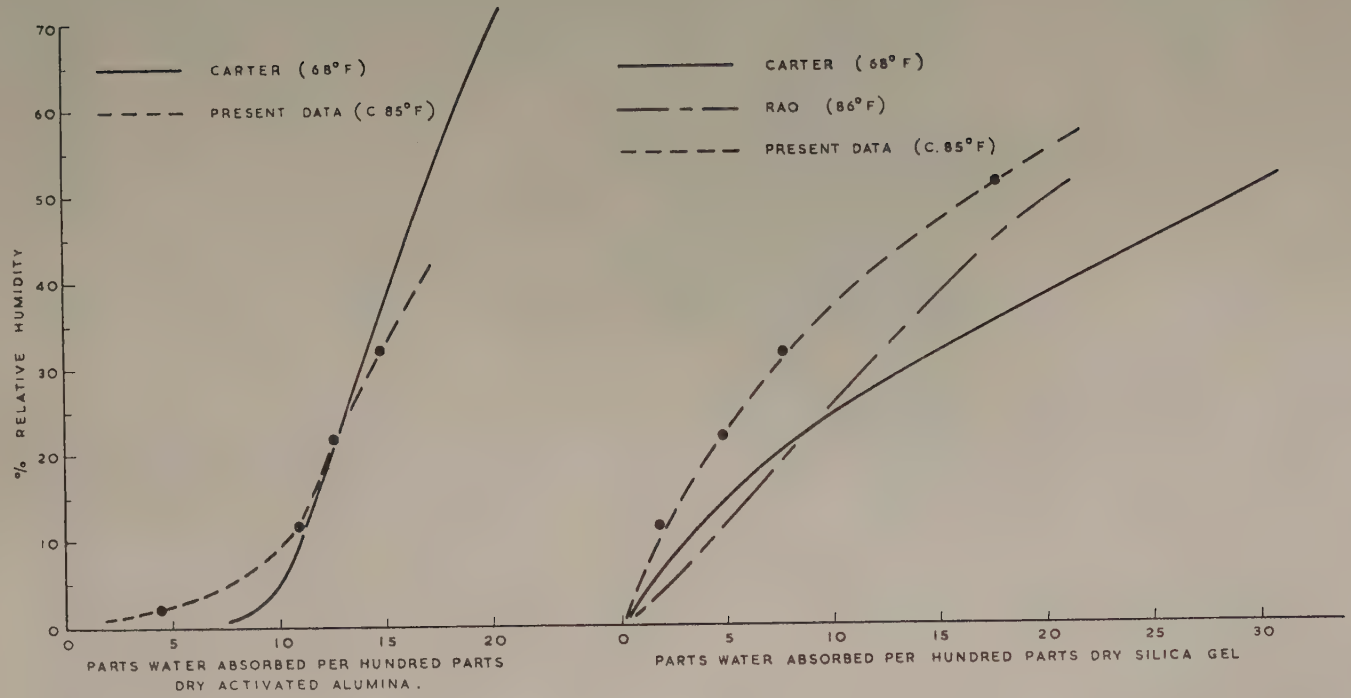

Figure 6. Water absorption of activated alumina and silica gel.

TABLE 10. WATER ABSORPTION AT c. 85°F

Percentage of dry desiccant

Relative humidity	Water absorption	
	Silica gel	Activated alumina
1.8%	—	4.5%
12.0%	1.9%	10.9%
22.0%	4.9%	12.6%
32.0%	7.7%	14.8%
52.0%	17.7%	—

rubber sheet will have at this humidity can be estimated from the data in Table 9 on the assumption that the water absorption is linearly related with relative humidity in the low humidity region. That this assumption is valid, has been shown by the work of LOWRY AND KOHMAN (1927) and approximately confirmed by the data in Table 8 in Section 3.

The relative humidity in equilibrium with silica gel containing 6.1% water is 26% (Figure 6), which gives a water content of the rubber of 0.08 to 0.09% (Table 9). At 2.5% R.H. (activated alumina containing 5% water), the water content of the rubber would be less than 0.01%.

Oven Drying and Drying over Activated Alumina

Although the use of activated alumina reduces the water content of sheet to a suitably low value at room temperature, it is possible that at higher temperatures and a similar humidity the sheet might liberate more water. If this were the case it would be preferable to use a higher temperature for determining the dry weight of a sample. The position is complicated however by the loss of volatile material other than water. CHAMBERS (1951) showed that oven drying in the United Kingdom at about 160°F causes a loss of volatile material other than water of about 0.05% for smoked sheet, and WOOD (1952) observed that approximately 0.1% of additional moisture and/or volatile matter is removed by heating rubber at 185°F after it has reached equilibrium over calcium chloride at room temperature.

The maximum temperature of drying envisaged was 200°F and this temperature was therefore selected as potentially the most useful temperature for oven drying of the samples, since the water removal would be greater than or equal to the removal obtained in the main drying investigation.

A comparison was therefore made of oven drying at 200°F/4%R.H. and drying over freshly dried activated alumina.

Experimental procedures. Oven drying was carried out in a constant-temperature chamber with forced circulation. A special weighing device enabled weights of the sheets to be measured in a compartment at the same temperature and humidity as the air used for drying. Corrections were applied for buoyancy effects caused by the density of air surrounding a sheet being different from that of the ambient air.

Eight sheets were prepared by the normal method and dried at 100°F and 60% relative humidity. Half of the sheets were then brought to equilibrium over activated alumina containing less than 1% of water and half brought to equilibrium at 200°F and the loss in weight measured. All samples were then returned to equilibrium at 100°F and 60% relative humidity and the reabsorption of moisture measured.

Results. The results given in Table 11 indicate that the oven drying at 200°F causes a greater loss in weight than drying over

TABLE 11. PERCENTAGE LOSS AND RECOVERY OF WEIGHT IN RUBBER SAMPLES

Activated alumina		Oven drying at 200°F	
% lost	% regained	% lost	% regained
0.27	0.28	0.63	0.30
0.20	0.28	0.79	0.37
0.23	0.29	0.79	0.33
0.24	0.24	0.61	0.32

activated alumina. The recovery of weight in the latter case is similar in magnitude to the loss (i.e. the moisture absorption is reversible), but the high temperature treatment produces a loss which is only partly reversible.

There are two possible explanations of this. The additional loss could be mainly volatile matter and about 0.05% water (the difference between the percentage weights recovered) or the additional loss could be entirely water, and the lower recovery of weight could be explained by a reduction in the water absorbing properties of the rubber caused by the high temperature treatment.

In any event the distinct possibility that there is a loss of about 0.4% of volatile material other than water renders oven drying at 200°F a doubtful method of water content determination.

Conclusions

The method selected for the determination of water content of air dried raw rubber sheets is the weighing of samples before and after equilibrating with an atmosphere in contact with activated alumina containing not more than 5% water. This brings the weight of the sample to within about 0.01% of the dry weight, which can be defined as the weight it would attain when vacuum dried at 0.01 mm mercury and 85°F.

The value of moisture content obtained is somewhat arbitrary since it is possible that a sheet dried over activated alumina might lose more water if its temperature were raised to say 200°F. The latter procedure is not desirable since there is a possibility that volatile material other than water would be removed at the same time.

The results also present a new factor to be taken into account when the effect of high temperature drying is considered. The sheets oven-dried at 200°F were held at this temperature for 10 days before equilibrium was reached. The period during which the loss of water-absorbing properties or of volatile material occurred is not known, but if either loss occurred during the initial period required to bring the sheets to an acceptable commercial level of dryness, one effect of high temperature drying would be to reduce the yield of product; this requires further investigation.

5. EFFECT OF DRYING CONDITIONS ON BLISTER FORMATION

Possibly the greatest limitation to the use of high temperatures, under the present market system of grading rubber, is the formation of blisters in the sheet. The mode of formation is not fully understood, but it is convenient to record here observations which give some indication of the mechanisms involved.

The Nature of the Gas and its Source

In these experiments a simple Orsat apparatus was used for determining oxygen and carbon dioxide contents of the gas samples. The volumetric accuracy of the apparatus was checked by determining the oxygen content of air, when dry and when saturated with water vapour. Oil was used in the measuring system instead of water. The value obtained for wet air was 19.7% oxygen, and for dry air 20.6% (theoretically 21%).

Blisters produced by drying sheets at 200°F were clipped under water and the gas collected. The analysis of the gas was 0.6% carbon dioxide, 19.5% oxygen and 79.9% of residual gas. The quantity of gas collected on occasions, however, amounted to as much as 0.3 c.c. per gram of serum originally present in the machined sheet, which is many times more than the solubility of air in water, 0.015 c.c. per gram at 86°F (COMEY AND HAHN

1921); thus the possibility appears to be ruled out that the blisters were caused merely by the release on heating of dissolved air from the serum.

The possibility of air diffusing in to replace the gas which originally formed the bubbles was examined. Blisters were blown in partially dried sheet by injecting carbon dioxide with a hypodermic syringe. The sheets were dried for two days at 120°F and the blisters clipped under potassium hydroxide solution. The presence of residual gas indicated the presence of air in the blisters.

In order to work with larger quantities of gas a sealed bag was made from sheets of machined coagulum. Using a hypodermic needle attached to a carbon dioxide cylinder, the bag was alternately inflated and deflated several times to expel the air, and then filled. The hypodermic needle was withdrawn and the point of entry sealed. The walls of the bag were translucent after three days at 120°F and the contained gas gave an analysis of carbon dioxide 37%, oxygen 14%, residual 49%, an analysis approximating closely to a mixture of air (63%) and carbon dioxide (37%). Since it was clear that air had passed through the walls of the rubber bag, even with a surface/volume ratio far smaller than any blister and a much lower temperature than that used in blistering experiments, it was concluded that further analyses of the gas from blisters in dried sheets were of little value.

One other result of this investigation is that gas recovered by heating two-day-old sheet serum was found to contain 66% carbon dioxide, which suggests that this gas may be largely responsible for blister formation: the solubility of carbon dioxide in water is about 0.66 c.c. per c.c. of water (KAYE AND LABY, 1918), which is much more in line with the observed volume of blisters.

Methods of Reducing or Eliminating Blister Formation

In an initial experiment a sample sheet from a coagulum prepared at pH 4.0 and machined to M.R. 0.032, and then steamed at atmospheric pressure, did not blister when subsequently dried at 200°F although there were several tiny blemishes on the surface.

This suggested that in the wet state the coagulum was sufficiently porous to allow the escape of the greater part of the gas during steaming. Plentiful blisters occurred with sheet that was not steamed, and it was noticed that these appeared during the first hour or two of drying.

Table 12 which gives the results of a further trial clearly demonstrates the effect of sheet thickness. The coagula were prepared at pH 4.0 and all machined to M.R. 0.032.

TABLE 12. EFFECT OF THICKNESS ON BLISTER FORMATION

Latex depth in.	Sheet thickness mm	Occurrence of blisters
1.5	2.7	Many
1.0	1.8	Few
0.5	0.8	None
0.16	0.3	None

The combined effect of thickness and humidity of drying is evident from Figure 7 which shows sheets prepared from coagula at latex depths of 0.87 in., 1.2 in., and 1.5 in. and dried at 200° F and relative humidities of 25%, 40%, 55% and 70%.

Conclusions

Although there may be considerable difficulties in preventing the formation of the type of blister encountered in these experiments at high temperatures, it appears to be technically possible to overcome them.

The mechanism of formation is not completely clear but a tentative explanation for the appearance of blisters during the first few hours of drying and the effect of humidity and thickness is as follows.

The sheet immediately before drying contains considerable quantities of dissolved gas and/or substances which decompose to yield a gas. The gas can be liberated before drying, without forming blisters, by heating the sheet while the surface is still wet to a temperature

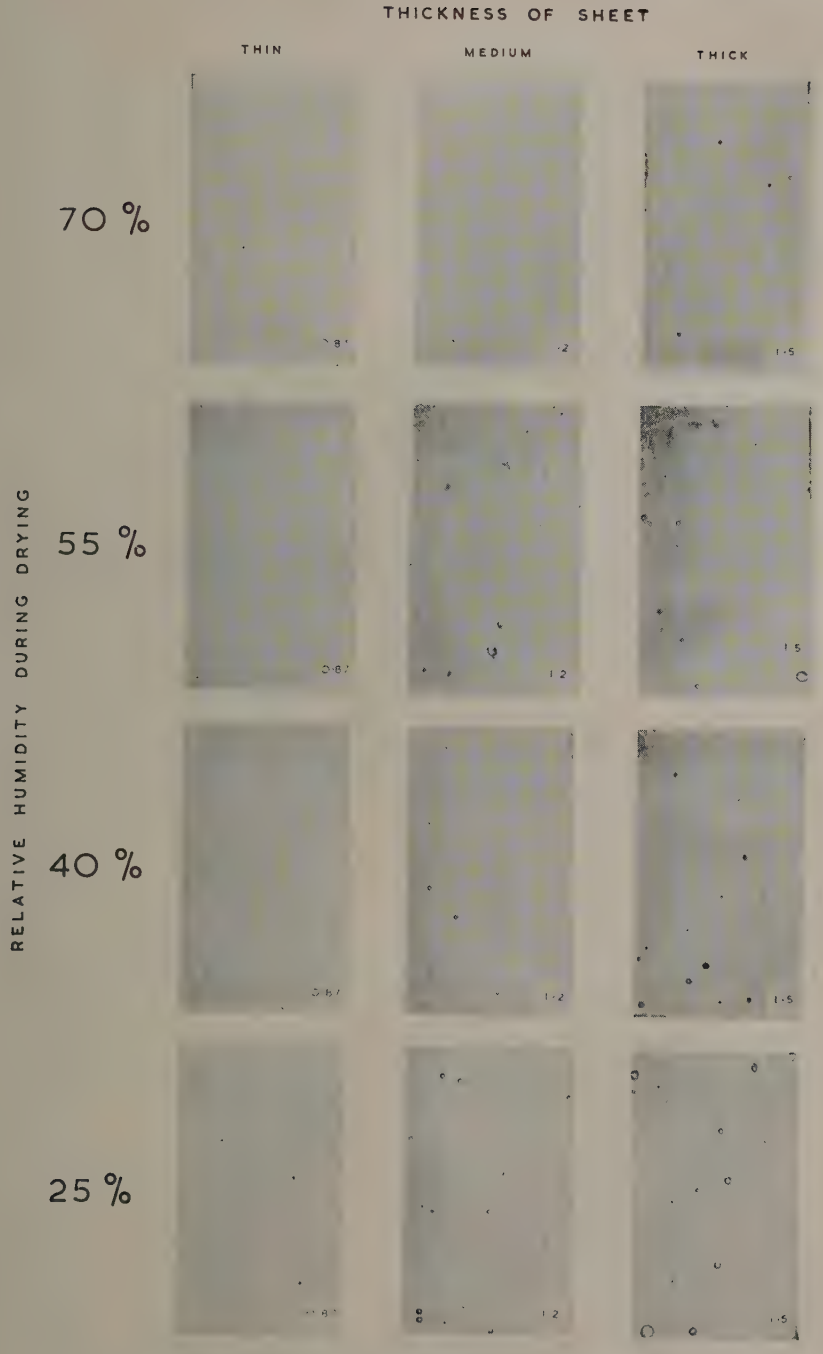

Figure 7. Blister formation at 200°F.

equal to or greater than the temperature of drying; steaming is an example of this.

With drying at low R.H. the wet bulb temperature—and thus the sheet temperature at the start of drying—is low, and gas remains dissolved in the serum. When the water content of the sheet has been reduced to about 15% there is a sudden rise in temperature which corresponds with the surface of the sheet drying out (e.g. Curve A of Figure 2). The rising temperature progressively increases the rate of expulsion of gas from solution and, at the same time, a relatively impermeable skin of dry rubber is formed on the surface so that conditions are provided for the development of blisters.

If a higher humidity is used the sheet temperature is higher (e.g., Curve B of Figure 2) and the sheet remains at this temperature in the wet conditions so that some gas is liberated without blistering. When the temperature rises at the first critical point there is less gas remaining to be liberated and blistering is reduced. The progressive decrease in blistering with increasing humidity is therefore associated with the progressive increase of wet bulb temperature.

The effect of thickness on blister formation is due to the lower gas concentration per unit area and to the increased ease with which gas can diffuse out from the thin sheet.

It is appreciated that blisters can arise by other mechanisms and these are at present under investigation.

6. EFFECT OF DRYING CONDITIONS ON TECHNOLOGICAL PROPERTIES

It was recognised at the outset that high temperatures would cause some softening of the rubber and that the quantitative effect would need to be determined. A casual observation had, however, also shown that a sheet immersed in hot water for measurement of water absorption became very much more tacky than a similar sheet kept at the same temperature in the dry state. It was thus thought that raising the humidity of drying could affect the degradation of the rubber quite apart from increasing the time during which the sheet is held at the drying temperature.

It was also considered that thickness of the sheet would have an effect on the rate of oxidation owing to the greater surface/volume ratio of such a sheet.

Effect of Elevated Temperature and Water Content on Raw Rubber Properties

It was considered that as the presence of water could affect the mechanism of the degradation of rubber it would be important to test the effect of conditions more extreme than those likely to be encountered in drying, so that any differences would be accentuated.

Experimental procedures. Six coagula were prepared at 1½ in. latex depth and pH 4.0 and machined to M.R. 0.032. Two sample sheets were cut from each and assigned randomly to the following three drying and storage treatments.

1	2	3
70 hrs at 140°F 15% R.H.	24 hrs at 200°F, 5% R.H.	24 hrs at 200°F. 100% R.H.
	46 hrs at 140°F, 15% R.H.	46 hrs at 140°F, 15% R.H.

The sheets at 100% R.H. were suspended horizontally over water in a vessel having a water-sealed outlet which kept the system at approximately atmospheric pressure.

The Mooney Viscosity and Williams Plasticity of the dry sheets were measured in triplicate after one week at room temperature, after 40 days at room temperature, and after 40 days followed by 24 hours ageing at 212°F (100°C).

TABLE 13. MOONEY VISCOSITY

Treatment after drying and before testing	Drying treatment 1	2	3
7 days at c.85°F	58	82	56
40 days at c.85°F	61	78	50
40 days at c.85°F plus oven ageing	68	39	27

TABLE 14. WILLIAMS PLASTICITY (D_{10}), MM. EFFECT OF DRYING CONDITIONS

Treatment after drying and before testing	Drying treatment 1	2	3
9 days at c.85°F	3.9	3.3	2.5
40 days at c.85°F	3.7	3.3	2.5
40 days at c.85°F plus oven ageing	3.5	2.5	2.2

Discussion of results. Increasing the temperature of drying from 140°F to 200°F causes an increase in the Mooney Viscosity (Table 13) of the rubber before oven ageing, in a manner similar to that found by WOOD (1952). When the high temperature treatment is at 100% R.H., either the hardening effect is inhibited or degradation is accelerated.

Ageing the samples after drying gives the following picture: storage hardening occurs for rubber dried at 140°F, whereas for rubber treated at 200°F storage hardening is outweighed by degradation, the process of degradation being accelerated by the maintenance of the rubber in the wet state during the period at 200°F.

The data in Table 14 show that degradation is more severe at 200°F than at 140°F and that again the presence of water during treatment at 200°F accelerates the degradation.

Recent work by SEKHAR (1958) has contributed to the elucidation of some of the mechanisms causing these effects. The main conclusion relating to drying is that at high temperatures the presence of water accelerates degradation.

Effect of Thickness, Temperature and Humidity

Since the presence of water was found to affect the degradation of the rubber it appeared likely that high humidities of drying would affect the properties more than low humidities. Experiments were therefore made to find the effect of the most severe condition of drying likely to be encountered (200°F/70% R.H.).

Experimental procedures. 16 coagula were prepared at pH 4.0 and machined to M.R. 0.032. Latex depths of 0.87 in., 1.2 in. and 1.5 in. were used. 4 sheets of each thickness were dried at 200°F/70% R.H. and 4 medium sheets were dried at 140°F/15% R.H. as a control.

Sheets were removed when translucent and stored for one week under laboratory conditions. The raw rubber was tested in duplicate for Williams Plasticity and Recovery before and after oven ageing for 24 and 48 hours. Samples were also compounded according to the A.C.S.1. specification and 6 discs of each compounded sample were vulcanised for 40 minutes at 284°F (140°C). Three discs were tested before ageing and three after 48 hours ageing in an oxygen bomb at 158°F (70°C) and 300 p.s.i.g. (B.S. 903: Part A19: 1956).

Results. The results are presented in Tables 15, 16 and 17.

Discussion of results. Before ageing both Williams Plasticity and Recovery are lower for the treated sheets than for the control, but the thin sheets, which have been subjected to the drying conditions for a shorter time, are less affected than the thick ones

TABLE 15. WILLIAMS PLASTICITY (D_{10}) MM. RAW RUBBER. EFFECT OF THICKNESS AND DRYING CONDITIONS

Sheet	Drying	Unaged	Aged 24 hours	Aged 48 hours
Thick	200°F/70% R.H.	3.2	2.8	2.7
Medium	200°F/70% R.H.	3.5	2.8	2.8
Thin	200°F/70% R.H.	3.6	2.8	2.6
Medium (control)	140°F/15% R.H.	4.1	3.8	3.8

TABLE 16. WILLIAMS RECOVERY, MM. RAW RUBBER

Sheet	Drying	Unaged	Aged 24 hours	Aged 48 hours
Thick	200°F/70% R.H.	3.7	3.5	3.3
Medium	200°F/70% R.H.	4.2	3.6	3.4
Thin	200°F/70% R.H.	4.3	3.5	3.2
Medium (control)	140°F/15% R.H.	5.3	5.8	6.0

TABLE 17. VARIOUS PROPERTIES OF VULCANISED RUBBER BEFORE AND AFTER AGEING

Properties after ageing shown in brackets

Sheet	Drying	Tensile strength kg/cm²	Elongation at break %	Modulus at 660 elongation kg/cm²	Hardness °BSI	Resilience at 70°C (158°F) %
Thick	200°F/70% R.H.	141 (159)	887 (777)	48 (87)	35.2 (38.2)	81.4 (84.9)
Medium	200°F/70% R.H.	135 (159)	883 (780)	48 (89)	34.3 (37.8)	81.0 (85.3)
Thin	200°F/70% R.H.	132 (156)	875 (769)	48 (87)	34.2 (37.2)	80.2 (85.1)
Medium (control)	140°F/15% R.H.	140 (144)	885 (757)	48 (89)	35.6 (37.9)	81.2 (85.1)

(Tables 15 and 16). The ageing properties of the sheets dried at high temperature are inferior; the recovery (Table 16) shows that storage hardening has occurred with the control but degradation has overshadowed this in the treatment sheets. No effect of thickness is established in the aged samples.

Table 17 shows that the drying treatment has no great effect on the properties of the vulcanised rubber. There is however some indication that reducing the thickness may adversely affect the properties, but further confirmation of this is required.

Conclusions

Temperature, humidity, and sheet thickness affect the properties of the raw rubber after drying; in particular the presence of water in the sheet accelerates degradation. Drying at 200°F/70% R.H. causes considerably more degradation than drying at 140°F/15% R.H. but the properties of the vulcanised rubbers are little different. The degradation and the lowering of the resistance to ageing of the raw rubber is of a significant extent from a practical point of view and means of prevention would probably be needed if such drying conditions were used: either revision of the processing of the rubber to give higher retention of natural antioxidants or the deliberate addition of synthetic antioxidants, e.g., polyamines (SEKHAR 1958).

GENERAL SUMMARY AND CONCLUSIONS

The objective of the work reported in the six sections above has been to obtain data on which to base a plan for a more detailed investigation of drying.

Factors have been considered which include the source of the latex, coagulation, machining, drying conditions, and the effect of these drying conditions on the yield of the product and its visual and technological properties. Methods have been devised firstly for the minimisation of variability in factors affecting the drying characteristics of sheet dried under

a constant set of temperature, humidity, and air speed conditions and secondly for the measurement of properties likely to affect drying. The presence of three phases of drying, which often occur with other materials and were shown by the work of Piddlesden to be valid for the drying of rubber, has been confirmed and studied in greater detail; these studies have revealed further complexities in the mechanisms involved in rubber drying. In the first phase it has been shown that under certain drying regimes syneresis can contribute materially to the loss of water, and in the third phase the raising of the humidity of the air can retard the drying rate to an extent not previously realised. The finding that the change in equilibrium water content associated with this retardation is small (Sections 2 and 3), has emphasised the need for accurate water content measurements if any correlation between equilibrium water content and drying rate is to be established; a convenient method of determining the dry weight of samples has therefore been developed. Means for the accurate determination of the wet weight of a sample during drying, not reported here, have also been devised and will be described in a further paper. Data have been obtained which point to high temperatures being more economic (Section 2: Conclusions) and the limitations set by visual and technological defects have been examined; it has been shown that high humidity treatments reduce blister formation but accelerate degradation.

In the course of these investigations further insight has been obtained into the mechanisms involved in:

(a) coagulum behaviour during machining and subsequent syneresis
(b) the changes of the dimensions of a sheet during drying and
(c) the formation of blisters and degradation at high temperatures.

An overall picture of the way in which the results impinge on the economics of drier design is as follows. The marked effect of humidity makes it clear that there is an optimum humidity of operation, at which the benefits of reduced fuel consumption at high humidities are balanced against the disadvantage of reduced output.

The balance is, however, altered if use is made of high humidity to reduce the tendency to blister formation and thus permit the use of higher temperatures. If the method were practicable up to very high temperatures, say 200°F, the limit might well be set by degradation of the rubber which is itself influenced by the humidity treatment it receives and the concentration of antioxidants in the rubber; thus a new set of factors would then determine the balance.

Another method of reducing blister formation—and so allowing high temperatures to be used—is to reduce the thickness of the sheet. From a general economic point of view, thin sheet is preferable because reducing sheet thickness gives a greater reduction of drying time than of the weight of rubber per unit of drier volume; the output from a given size of drier would therefore be increased.

The introduction of the idea of an optimum thickness, however, takes one into a field where not only the drying operation itself must be considered, but also on one side the processes required to produce the wet sheet, and on the other the handling of the dry sheet to get into a form suitable for shipment. With the present methods of manufacture, although drying might be cheaper with thin sheet, the cost of preparation and packing would be greater. The present sheet thickness of about 0.1 in. is the outcome of many years of practical experience and development and is probably very near to the optimum.

If however some of the limitations were removed by the introduction of novel methods of coagulation, machining and packing, in which the balance of costs was different, then the optimum thickness might well be different from that in current use. If continuity of operation, and mechanisation, were associated with these changes the ratio of capital to operating charges would probably increase, and means of reducing drying times (i.e., reducing size of drying plant for a given output) would assume a new importance.

Considerable attention has been devoted by the various research institutes in the East to the possibilities of new coagulation and preparative techniques but it is clear that before the economics of a unified process can be assessed, further more detailed information is required on the effect of drying conditions on drying rates and quality. The present paper supplies data essential to the planning of the main programme designed to provide this information. The experimental part of this programme has already been carried out, but the analysis and assessment of the observations are not yet complete. It is hoped to publish the results of this further work in 1960.

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